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MILLIMETER WAVE TECHNOLOGY POLICY

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906C3823 Tokyo DENKI TSUSHIN GIJUTSU SHINGIKAI MIRIHA GIJUTSU IINKAI HOKOKU in Japanese May 89, pp 1-49, 1-21

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[Text] Foreword

Today, radio waves are used in a wide variety of fields, beginning with broadcasting and including various radars, remote-sensing systems, and high-frequency heating equipment. Radio waves have thus come to play an important role not only in the everyday living but also in industry and scientific research, and without them modern socioeconomic activity would not be possible.

Until now, electric waves have mainly been used in the frequency bands below the microwave band; with some exceptions, frequency bands above the millimeter wave band have not been tapped because, among other reasons, the need to use millimeter wave technology has yet to be fully established. Technical development of the millimeter wave band has advanced in recent years, however, and the physical characteristics of the millimeter wave band have led some to propose new uses that are quite different from the ways electric waves in the frequency bands below the microwave band have been used. Development of millimeter waves is expected.

Efforts to develop practical application of the millimeter wave band are going on overseas, including a project to develop a millimeter wave integrated circuit being undertaken in the United States and a study on ways to promote the use of millimeter waves in Great Britain.

In accordance with Inquiry No 39, "Technical Problems Associated with Utilization of Millimeter Waves (30~300 GHz)," (Posts and Telecommunications Technology No 67, dated 27 June 1988), two subcommittees of the Millimeter Wave Utilization Technology Committee of the Telecommunications Technology Council--the Millimeter Wave Utilization Subcommittee and the Subcommittee for Development of Millimeter Wave Utilization Technology--have been deliberating on the future prospects of millimeter wave technology and problems for development of millimeter wave technology and have put together this report. Chapter 1 describes the current status of millimeter wave utilization in Japan and the future use of the waves, Chapter 2 describes the current status of millimeter wave technology and its technical tasks, and Chapter 3 describes measures for promoting widespread utilization of millimeter waves and for promoting the technology's development.

We expect this report will contribute to expanded use of millimeter waves in Japan.

Chapter 1. Current Status of Utilization and the Future

Section 1 in this chapter describes the circumstances leading to allocations of frequencies and the ways millimeter waves are being used currently. Section 2 forecasts where and how millimeter waves will be used in the future and the demand for them. Section 3 discusses frequency bands that will be needed for millimeter wave systems in the future.

1.1 Frequency Allocation and How Frequencies Are Being Used

1.1.1 Circumstances Leading to Frequency Allocation and Current Status

With advancing use of radio waves, frequency allocation has been expanding into higher frequencies. Frequencies in the millimeter wavelength region were allotted for the first time in 1959 at an international meeting of government telecommunications agencies. The meeting expanded frequency bandwidth used at the time (10 kHz to 10,500 MHz) to 10 kHz to 40,000 MHz and replaced the frequency unit used at the time, gigacycles per second, with a new unit, gigahertz (GHz). At the same time it established new radio wave services, including space telecommunications, radio astronomy, and radiolocation, and allotted millimeter wavelength frequencies for these operations.

In 1971, a meeting of governmental telecommunications agencies expanded the upper limit of allotted frequencies to 275 GHz, and assigned frequencies for the operation of fixed satellite communications systems. At this time, the agreement called for frequency assignments for new services such as radio navigation satellites.

Furthermore, a 1979 meeting of the government telecommunications agencies drastically revised frequency allocation. It adopted a Japanese proposal to expand the upper limit of frequencies from the then 275 GHz to 400 GHz. In addition, revisions were made in the operational plans of services that were assigned frequency bands smaller than the 275 GHz.

Japan reviewed its domestic allotment of frequencies in accordance with the revisions in the international allotment of frequencies. Currently, frequencies in the millimeter wavelength region are assigned to operations as shown in Figure 1.1.

1.1.2 Current Status of Utilization

Increasingly higher frequencies are being used to keep pace with advances in radio wave technology, exploration of new fields where radio waves can be put to good use, and accumulation of knowledge on radio wave operations. In Japan, almost all frequency bands in the millimeter wavelength region (10~30 GHz) or below are being put to use. At 20~30 GHz, for example, fixed operations (telecommunications businesses) are being carried out using frequencies below 21.2 GHz, mobile operations (telecommunications businesses) are being carried out at 21.2~22.5 GHz, fixed operations and ground mobile operations (cable TV broadcast) are being carried out at 23.0~to 23.6 GHz, mobile businesses (telecommunications) are being carried out at the 25.25~27 GHz, and fixed

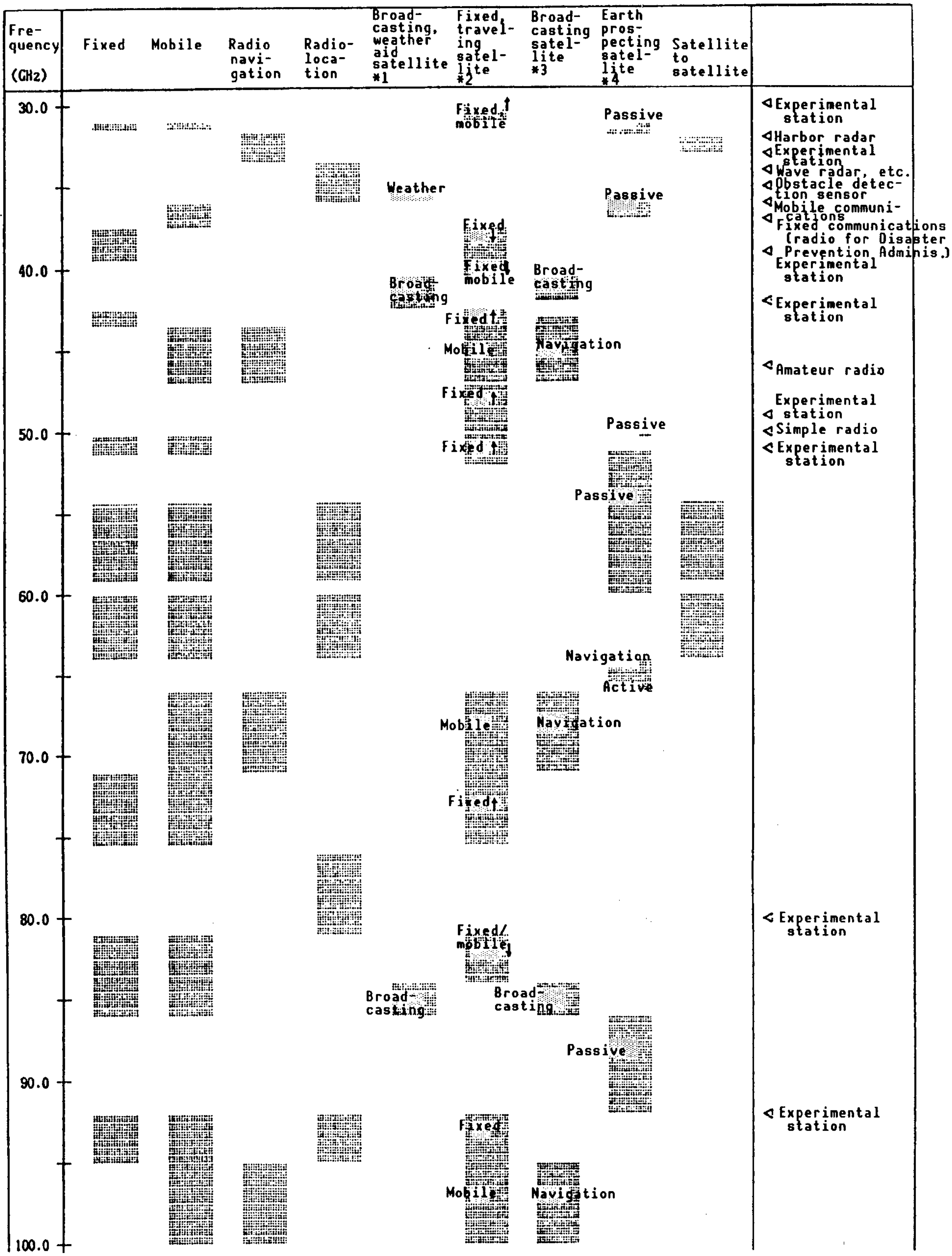
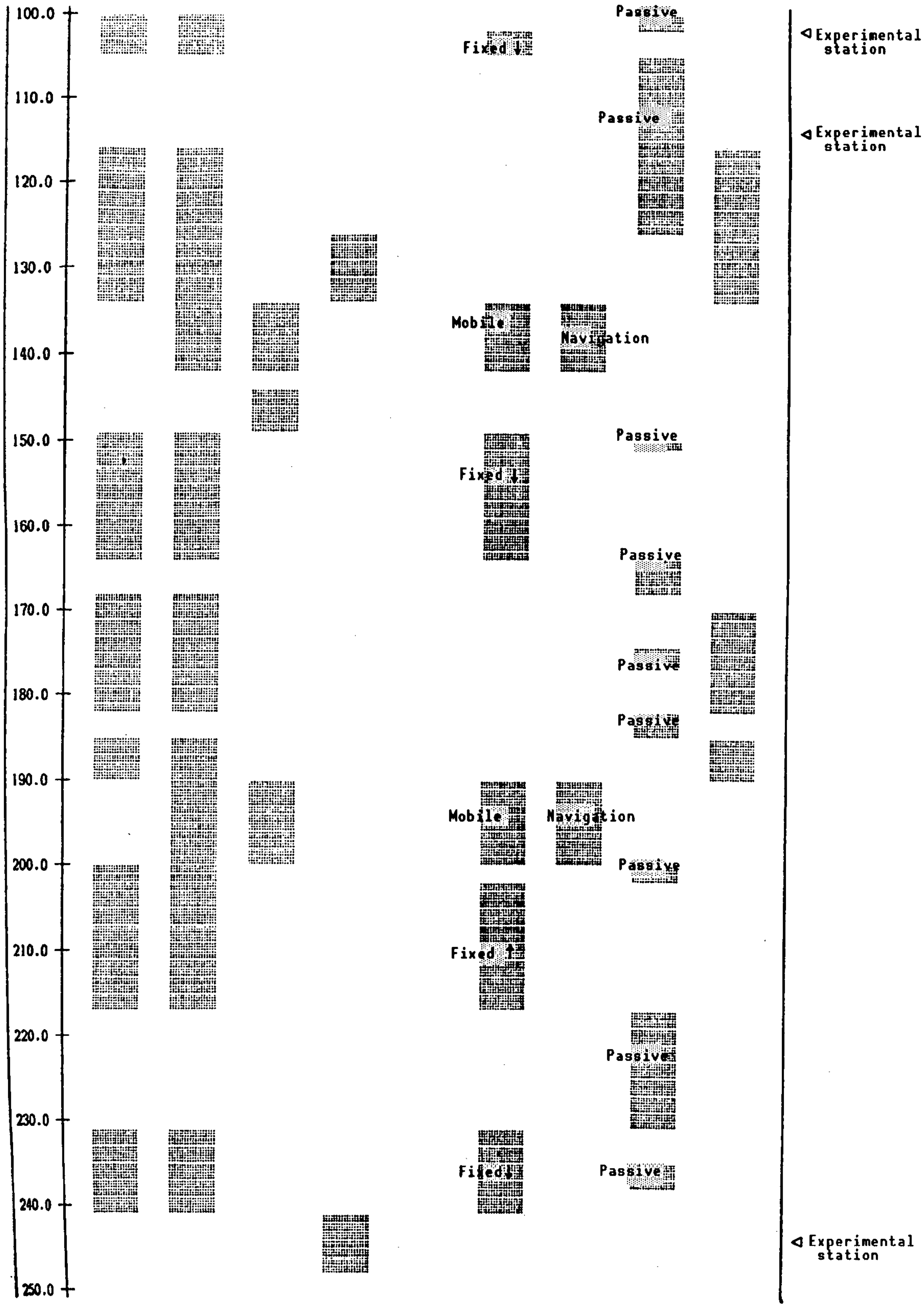
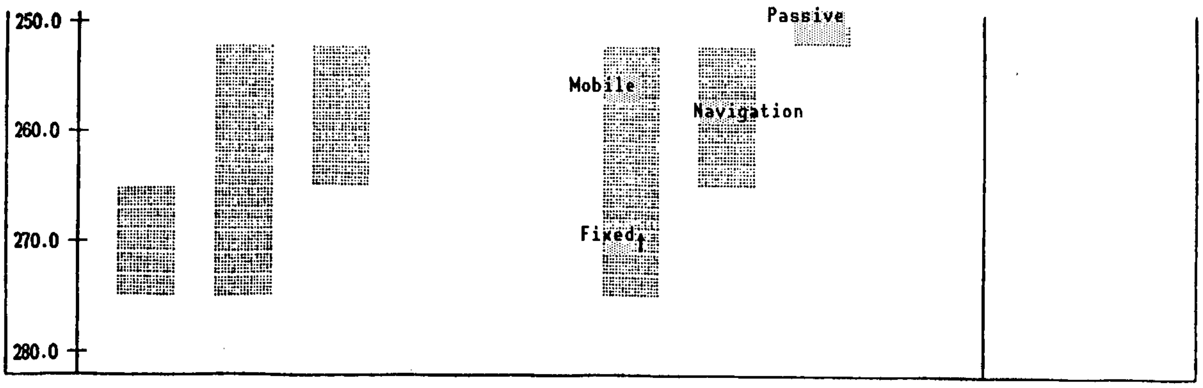


Figure 1.1 Current Assignments of Frequencies in Millimeter Wave Region

[Continuation of Figure 1.1]



[Continuation of Figure 1.1]



Notes: 1. Broadcasting operation and weather aid operation.

2. Fixed satellite operation and mobile satellite operation. (↑) denotes from earth to space, and (↓) denotes from space to earth.

3. Broadcasting thermal load operation and radio navigation satellite operation.

4. Capable of obtaining information concerning the earth's characteristics and its natural phenomena from the passive detector on board the earth satellite; can also obtain information from the active detector on board.

satellite operations (earth stations for CS-3, etc.) are being carried out at 27~30 GHz. Almost all remaining frequency bands are being used either in radio astronomy or being considered for such future operations as broadcasting and satellite broadcasting.

Above 30 GHz, frequencies at 34 GHz band were assigned to an experimental station of the Meteorological Agency for the first time in 1961. Since then, millimeter radio waves have been assigned for various operations, but as of now all commercial stations are operating at bands below 50 GHz. Among the major millimeter wave systems in operation at present are the following:

(1) Fixed Operations

The 37.5~39.5 GHz band has been assigned to radios of the central disaster-prevention administration and others since 1980.

(2) Mobile Operations

The 36.0~37.5 GHz band has been assigned for use for image transmission for public businesses.

(3) Radiolocation and Radio Navigation Operations (Sensors, radars)

Among the major items in this category are harbor radars, obstacle-detecting sensors at railroad crossings, and wave observation radars. A harbor radar that can detect shipping movements has been in operation in Osaka Bay since 1964. Obstacle-detector sensors have been operating at specified railroad

crossings in the Kanto area since 1983, and their number has grown to more than 30. Wave observation radars are operating at about 20 locations.

(4) Simple Radios

Frequency bands of 50.4~50.65 GHz and 50.9~51.15 GHz are reserved for simple business radios. Major functions are data transmission and image transmission. The number of such radio stations has been increasing at about 200 stations a year for the past several years, reaching about 1,000 stations by the end of 1988.

1.2 Use of Millimeter Waves in the Future

1.2.1 Fields and Modes of Future Use

Millimeter waves have several advantages over those below microwave band; they have a broad bandwidth and millimeter wave systems can be built small and lightweight with relative ease. Millimeter waves, however, are vulnerable to attenuation by rain and atmospheric absorption. Therefore, they are most effective in such applications as signal transmission that have short propagation distances but require large bandwidths such as image communications and high-speed data communications in mobile communications systems. They can be used most effectively in sensors that exploit their characteristics--atmospheric absorption as a result of interactions on the atomic or molecular level. Millimeter waves are expected to become actively used mainly in these fields in the future.

Compared with light waves, millimeter waves are less vulnerable to the effect of solar light, fog, snow, dust, mud or vibration, and they can be focused into a beam easily. However, before millimeter waves can realize their full potential, an oscillator with stabilized frequencies and high output power must be developed and the millimeter wave systems will have to be downsized to levels equivalent to light-based systems.

Millimeter waves also are less vulnerable to atmospheric turbulence than ultrasonic waves, and thus have advantages in sensors that require a relatively large atmospheric space for detection.

Even in those fields where characteristics of millimeter waves can be exploited to the highest degree, millimeter wave systems will need to be reduced in size and be produced at less cost if they are to find widespread use.

The following describes the fields where millimeter waves are expected to be applied in the future and their modes of use, and Table 1.1 lists the millimeter wave systems.

Table 1.1 Millimeter Wave Systems in the Future

Field	Division	Application
Fixed communi- cations		Terminal circuits for broad bandwidth ISDN Terminal circuits for satellite telecommuni- cations circuits A link between music hall and satellite studio for broadcast programming Short-distance fixed communications at con- struction site or dam Cordless ITV camera ITV system for monitoring urban traffic High-vision cable television (CATV) CATV signal branching system
Mobile communi- cations	Train	Transmission system inside tunnel, such as satellite broadcasting Millimeter wave large-capacity communications for trains (installed only at train stations) Millimeter wave large-capacity communications for trains (installed throughout the railway system) Platform monitoring system Control of distance between trains
	Cars	Interactive road-car exchange of communication/ traffic information
	Portable	Wireless ITV for construction work Short-distance FPU Portable multiplex circuits for disaster Binocular-like transceiver Broad bandwidth, small-zone mobile communica- tions by leakage cable Microcellular system (compatible with ISDN) Wristwatch telephone (small zone) Wireless camera (for broadcasting) Wireless video monitor (for broadcasting) Remote control and monitoring system (for agriculture, civil engineering)
	Aircraft	Monitoring power transmission line by unmanned aircraft Stratospheric communications

[table continued]

[Continuation of Table 1.1]

Field	Division	Application
Communications within a local area or closed space		Local high-speed data communications networks (ISDN, LAN compatible) Bidirectional paging system in an office POS terminal communications system Vehicular control system Mobile communications (small size, lightweight) in tunnels and underground shopping malls Emergency communications in underground shopping malls
Broadcasting		Small-area local broadcasting
Satellite	Communications	Personal satellite communications system Data relay between high-altitude platforms (HAPP) Intersatellite communications (ISL) Communications in vicinity of space stations
	Broadcasting	Satellite broadcasting
	Radio navigation	Satellite navigation system for the private sector
	Remote sensing	Measuring cloud thickness Satellite-borne radar for measuring rainfall Satellite-borne millimeter wave submillimeter radiometer
Sensors, radars	Noncontact card systems	Millimeter wave ID system (for use on people) Millimeter wave ID system (for use on cars) Millimeter wave ID system (for use on objects) Noncontact integrated circuit card
	Location identification object	Identification system for locations System for searching out objects (parking area control, animal control) Airport surface search radar (ASDE) Directional control of digging machine

[table continued]

[Continuation of Table 1.1]

Field	Division		Application
[contd] Sensors, radars	Obstacle detection/collision prevention	Car	Obstacle detection for car; car-to-car distance warning; collision prevention sensor; detection of obstacle at the rear of a car Radar for snow plow, road patrol car (including the capability to detect object underneath snowfall) Follow-up control for car
		Ship	Berthing system for ships Radar for preventing ship collision Port and harbor monitoring system
		Aircraft	Helicopter-borne collision warning sensor Landing support system for helicopters
	Intruder detection		Sensor for detecting intruder or intruding object (inside and outside of house) Electric wave fence (leakage cable type) Electric wave fence (reflector type)
	Other		Vehicle-to-ground speed sensor (antiskid system) Car sensor for detecting road conditions Car sensor for detecting road contours Radar detector for speed violation control Inspection of personal possessions, including nonmetallic objects Landslide sensing radar Water gauge (rivers, dams) Level gauge (inside tanks, etc.) Snow cover meter Wave observation radar Measurement of (liquid) flow in water pipe Meter for measuring flow of powder Measuring system of vapor, VI meter Fire detector, oxygen density meter Measurement of surface accuracy of reflecting mirror Measurement of thickness of steel plate Metal plate thermometer In vivo measurement of temperature (millimeter wave thermography) Measuring device of oxygen pressure in blood Blast furnace insert profiler [continued]

[Continuation of Table 1.1]

Field	Division	Application
[contd] Sensors, radars	[contd] Other	Radio wave/acoustic wave common use radar (RASS radar) Measurement of plasma in nuclear fusion Rainfall intensity recorder Weather radar Aircraft-borne rainfall zone scattering meter Air turbulence detection system
Use as energy media		Electron cyclotron resonance heating of nuclear fusion plasma; millimeter wave electric power transmission system Hyperthermia

(1) Fixed Communications

In fixed communications, radio signals such as microwaves and cable signals can be used as alternatives to millimeter waves. Even millimeter waves with potentially large capacity cannot match the communications capacity of optical fibers, but millimeter waves are more advantageous in places where it is difficult to lay fiber optic cables for physical or economic reasons.

Compared with microwaves, millimeter waves have shorter propagation distances but are capable of large-capacity communications thanks to their broad bandwidth characteristics. Furthermore, when used for short-distance communications, millimeter waves are scarcely affected by rain, so they can be put to good use in such fields.

However, as millimeter wave technology stands now, millimeter wave systems are inferior to other means of communications, so their costs need to be brought down.

Among possible application of millimeter waves under consideration are terminal circuits for the broad-bandwidth integrated services digital network (ISDN), terminal circuits for satellite communications channels, image transmission for monitoring urban traffic, programming links in short distances such as between satellite studios, and image transmission to and from a dam construction site.

(2) Mobile Communications

Because millimeter wave systems can be built much smaller and more lightweight than those needed for lower frequency bands, they can be more easily incorporated in mobile communications systems and made more transportable. Millimeter waves have shorter propagation distances than those in lower frequency bands, but their broad bandwidth characteristics make it possible to

develop mobile communications systems for transmission of images and data requiring wide bandwidths.

Among other possible applications are mobile communication using leakage cables or cellular systems, communications between a station or some other point and a train (data, telephones, FAX, images), communications between road vehicles, image transmission for broadcasting (wireless cameras, wireless video monitors, short-distance field pick up (FPU), industrial TV (ITV) image transmission to and from a construction site, systems for monitoring transmission power lines coming from the flight band, communications in the stratosphere, image transmission during disasters or emergencies, and binocular-like transceivers that permit communication while looking into another person's face.

(3) Communications Within a Local Area and a Closed Space

When using millimeter waves within a local area or a closed space, the radio waves generally need to travel only short distances, so their disadvantage—large attenuation by atmospheric absorption—is not much of a problem. As offices have become increasingly automated in recent years, more use will be made of radio signals to interconnect terminals, and in this area a great deal is expected from millimeter waves with broad bandwidth characteristics. In addition, millimeter waves can easily propagate through a flame (plasma) and, thus, are expected to be used as a means of communications during fires in underground shopping arcades.

By taking advantage of the characteristics described above, it is expected that millimeter waves will be used in such applications as intraoffice ultrahigh-speed data transmission, intraoffice paging, wireless POS terminals, and mobile communications in underground shopping malls.

(4) Broadcasting

Because millimeter waves have a propagation distance shorter than those for conventional frequency bands below the microwave, they may be tapped for broadcasting to limited areas, such as within an individual city, town, village, a block or other limited area.

(5) Satellite-Related Use

When using millimeter waves for satellite operation, transmission losses are extremely large, so large transmission powers are needed. However, millimeter waves make it possible not only to provide a service to a limited area but also to provide broad bandwidth transmission. In outer space communications, the millimeter wave systems need to be built small and lightweight as light-based systems, but the millimeter waves are free from attenuation by atmospheric absorption and rain-caused attenuation is not a factor. Another advantage is the ease of directional controls of the antenna, made possible because the millimeter wave beam width is larger than that of light. Among possible applications of millimeter waves are personal satellite communications, data relays between high-altitude platforms (HAPP), communications near

or around a space station, intersatellite communications (intersatellite links), satellite broadcasting, and remote sensing. Of the modes of communications listed above, experiments are to be made on personal satellite communications and intersatellite communications using the Engineering Test Satellite VI (ETS-VI) scheduled for launch in 1992, and development of the systems and equipment is under way.

(6) Sensors and Radars

Among the major applications of sensors and radars under consideration are noncontact card systems, location identification objects, intruder detection, obstacle-detection, and collision-avoidance radar.

a. Noncontact card systems

These systems will use millimeter wave noncontact cards in such operations as human entry or exit from an office and bank deposits and withdrawals.

A system's coverage will depend on how it is to be used, but when the area to be served is a space several meters to several tens of meters in radius, the millimeter waves' propagation characteristics will be enough to do the job. Moreover, the directivity can be freely changed depending on the use from a narrow beam to a broad beam. At present, systems on frequency bands below the microwave are being used commercially but their transmission capacities are smaller than those of the millimeter wave band, which makes an exchange of a large volume of data in a short timespan impossible. Therefore, the use of millimeter waves will be highly effective.

In terms of cost, infrared rays or light have the advantage over millimeter waves at present, but their poor penetrability requires the user to take his card out of his pocket, and this extra trouble makes light-based systems inferior to millimeter wave-based systems.

b. Location identification object

A location identification object determines a person's position by receiving radio signals emitted by base stations in several different locations using a mobile unit. When used in a limited area, the transmission loss of the waves caused by rain is not much of a problem, and an effective system can be built by using millimeter waves.

In the object search-and-detection-system, base stations are established at several locations within a large-scale construction site, a large farm or a natural environment. These stations emit millimeter waves to determine the position and speed of mobile units (vehicles, ships, animals) and identification is needed for multiple units. Compared with microwaves, millimeter waves can be focused into a narrower base, which raises the accuracy.

c. Intruder detection

In this system, an intruder detected by using the radio wave cutoff that occurs when the intruder or object passes through a millimeter wave propagation path or by exploiting the changes in the state of radio wave reflections. This system is applicable not only inside a house but also at railroad crossings, on the periphery of a plant site, or on the periphery of a dangerous object.

Since the millimeter wave has a wavelength shorter than that of the microwave, it features high resolution. Furthermore, since the required propagation distance is generally shorter, the propagation characteristics of millimeter wave band are not much of a problem. Compared with millimeter waves, light-based systems are more vulnerable to the influences of solar light, fog, and vibrations, and require relatively larger amounts of maintenance.

Ultrasonic systems are less vulnerable to the influences of rain and fog, but they are affected by wind and other noises. Magnetic sensors and vibration sensors being widely used at present need to be installed in large numbers as the size of the house increases, requiring a large volume of wiring. To cope with this problem, a millimeter wave system has been proposed.

d. Obstacle-detection and collision-avoidance radar

Experiments have begun on an automobile collision-prevention radar, a helicopter collision-warning sensor, and a berthing aid for ships.

Automobile collision-prevention radar detects the relative distance and the relative speed between the automobile and an obstacle, emits an alarm, and activates automatic controls. Compared with light waves, millimeter waves are less vulnerable to the influences of solar light, fog, snow or mud and are also unaffected by the color or material properties of the target. Moreover, millimeter waves are less affected by air turbulence than are ultrasonic waves. Compared with frequency bands below microwave, millimeter waves have larger Doppler shift, enabling accurate measurement of relative speed. Because this is a system on which the life or death of the driver is dependent, system reliability is the first requirement.

The helicopter collision-warning sensor detects flying objects, power transmission lines, etc., and warns the pilot when they are too close. Because this system requires high resolution, the millimeter wavelength band is more advantageous than lower frequency bands.

The ship berthing aid system provides the skipper of a ship information about the distance between the berth and the ship's speed and is designed to prevent the ship from bumping into the pier. Similar systems based on microwaves are being put to practical use at present, but the use of millimeter waves would be more accurate.

e. Others

Other prospective applications of millimeter waves are in air-to-ground sensors, road condition detection sensors, water level meters for dams and rivers, level gauges inside a storage tank, snow meters, oxygen density detection sensors, millimeter wave thermography, blast furnace insert profilometers, short-distance radio acoustic sounding systems (RASS radar), weather radars, rainfall meters, and atmospheric turbulence detection systems.

(7) Use as an Energy Source

The energy absorption efficiency of millimeter waves is higher than that of the microwave, which may be exploited for resonance heating of plasma in nuclear fusion.

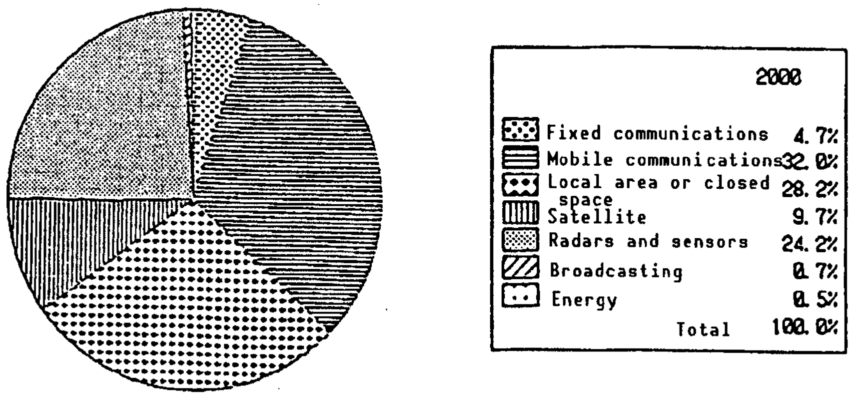
1.2.2 Estimating Demand for Millimeter Wave Systems

As stated in paragraph 1.1.2, some systems are already in operation, but the majority of the systems listed in Table 1.1 are expected to find commercial application between 1990 and 2000. When projections are made as to when a system will be commercialized, the number of installation, its price, and its lifetime for each of the millimeter wave systems, the total market for such systems is expected to reach ¥40~200 billion by the year 2000 and ¥200 billion to ¥1 trillion by the year 2010. Figure 1.2 shows the projected ratios of demand for various categories of millimeter wave systems, calculated on their monetary values, for the year 2000 and the year 2010. The largest increases in demand are expected to be found in mobile communications, local area and closed space communications, and sensors and radars, among others. These three applications are expected to account for more than 70 percent of the total demand for millimeter wave systems.

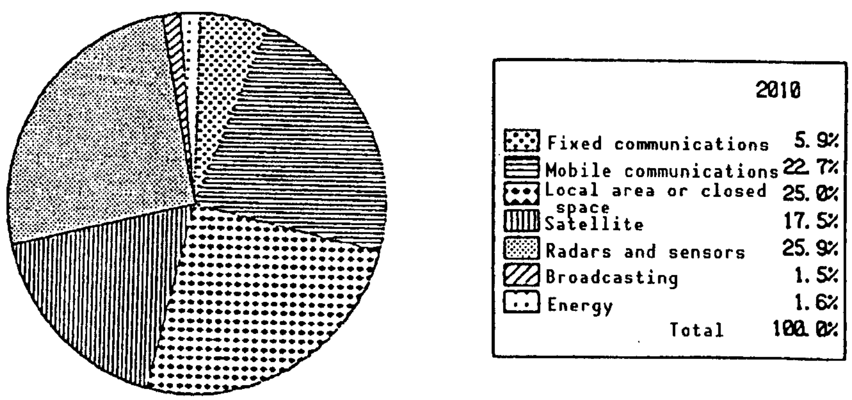
At present, annual output of radio wave systems (radio communication systems, broadcasting equipment, radio-applied equipment) reached ¥733.4 billion (in 1987, according to the Communications Industries Association of Japan). If we assume that output will keep increasing at an annual rate of about 10 percent, the average increase rate over the period from 1977 to 1987, the market will expand to about ¥2.55 trillion by the year 2000 and to about ¥6.6 trillion by the year 2010. Add to these figures the demand for millimeter wave systems, and the total market is expected to expand as shown in Figure 1.3. Millimeter wave systems are expected to reach 7 percent of the total output of radio-wave-related systems and equipment by the year 2000 and 13 percent by the year 2010 at the maximum.

1.3 Frequency Bands for Millimeter Wave Systems in the Future

For millimeter wave systems to be established in the future, the certain frequency bandwidths and the usable frequency bands will be the determining factors for the timing of the establishment as well as further exploration of frequency. The following describes the frequency bandwidths necessary for future millimeter wave systems and the frequency bands that will be used, while giving consideration in international allotments of frequencies and the wave's propagation characteristics.



Year 2000 (total: Y40 billion)



Year 2010 (total: Y200 billion)

Figure 1.2 Demand for Millimeter Wave Systems by Category, Calculated in Terms of Monetary Value

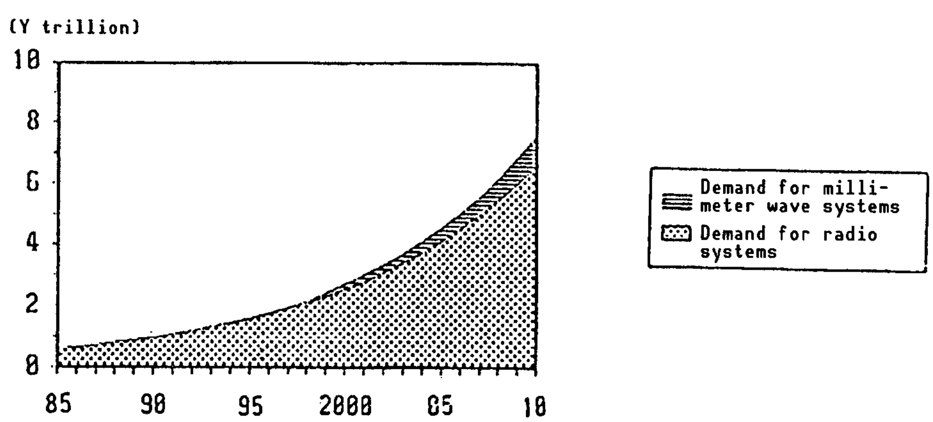


Figure 1.3 Demand for Radio Systems in the Future

1.3.1 Frequency Bandwidths Needed for Future Millimeter Wave Systems

The widths of each of the frequency bands allocated for major categories of operation and the frequency bandwidths needed for realizing the millimeter wave systems in the future are shown in Figure 1.4 for comparison. In the case of the radiolocation operation, a field where the use of the millimeter wave band is expected to grow, a frequency bandwidth of about 26 GHz is considered necessary to accommodate new millimeter wave systems expected in the future and, given the frequency allotment for the operation, the use of frequencies up to about 140 GHz will become necessary. Fixed and mobile operations will need frequency bands up to about 90 GHz. Few of the systems described above have an absolute need for any specific frequency bands, but with the current state of technology, a majority of the systems, it is said, require frequency bands below 70 GHz. Therefore, in promoting development of millimeter wave technology, the goal should be a technological capability that would enable the use of frequency bands beyond 100 GHz. In Figure 1.4, the frequency bands that need to be developed are tabulated for independent categories of operation, but, in promoting research on the development of practical systems in the future, attention will have to be paid to effective utilization of frequencies. In other words, researchers will have to consider such matters as how to accommodate as many systems as possible on the same frequency band and the joint use of the frequency band allotted to a group of different categories of operation.

1.3.2 Frequency Bands for Use by Millimeter Wave Systems in the Future

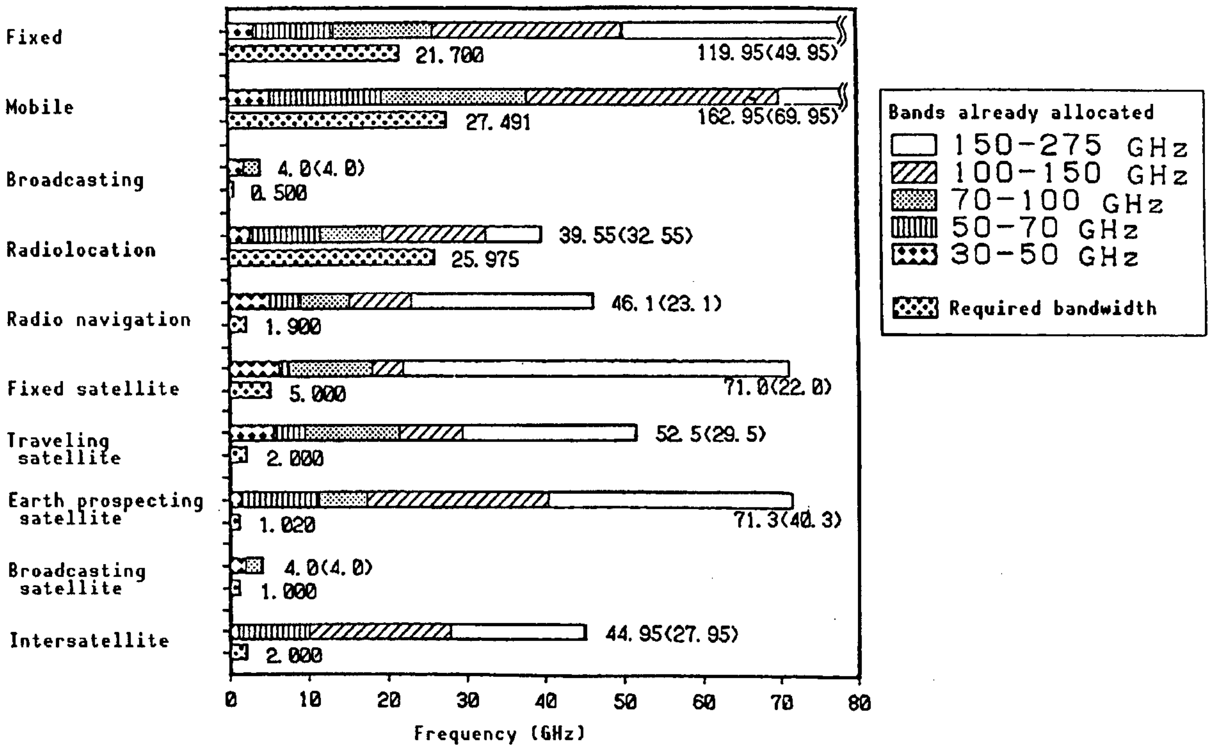
As the use of radio waves has grown, increasingly higher frequencies have come to be used. In the future, the millimeter band is expected to be used more and more in those kinds of applications where frequencies are currently being used in fixed and mobile radio operations. At the same time the millimeter wave is expected to find new applications by taking advantage of its broad bandwidth and propagation characteristics. For each of the listed millimeter wave bandwidth regions, the following describes the assignments of millimeter wave bands, and explains the propagation characteristics of the band, existing systems operating on the band, and projected future systems for the band.

(1) 30~50 GHz

Radio wave propagation characteristics within this region are that the attenuation by rain becomes greater at higher frequencies.

On the other hand, since this region is a window region for millimeter waves least susceptible to atmospheric absorption, many bands are allocated for satellite telecommunications.

Further, frequencies in this region are assigned to a variety of operations including fixed communications, mobile communications, radiolocation, radio navigation, fixed satellites, traveling satellites, and broadcasting satellites.



Note: Figures in upper row: Frequency bandwidths allocated in millimeter wave region (( ) is a subtotal of below 150 GHz)
Figures in lower row: Bandwidths needed for future millimeter wave systems.

Figure 1.4 Frequency Bandwidths Allocated for Major Categories of Operation and Required Bandwidths for Millimeter Wave Systems

Frequencies in this region at present are used in such applications as fixed radio operations of the central disaster prevention administration, official or public communications of images as a mobile mode of operation, harbor radars, obstacle detectors at railroad crossings, wave observation radars for radiolocation or radio navigation, and experimental stations. Experimental stations for satellite-to-satellite communications and communications with stationary satellites are also scheduled for these frequencies.

Among the projected applications of millimeter waves are short-range image and data transmission, the distance least susceptible to attenuation by rain; monitoring radars at ports and harbors; weather radars; broadcasting satellites; feeder lines for broadcasting satellites; fixed satellite communication; satellite-to-satellite communication; personal satellite communication; and small-area local broadcasting. The 30~50 GHz band has already been partially exploited, and applications are expected to increase in the future.

(2) 50~70 GHz

Radio wave propagation characteristics within this region are that atmospheric absorption reaches a peak in the vicinity of 60 GHz, attenuating the radio signal to a great extent. As a result, the spatial re-use of the same frequency becomes possible in another area only a short distance away. The rain attenuation approaches a saturation with little dependence on frequency.

In this region, many bands are allocated for various operations, including fixed communications, mobile communications, radiolocation, and satellite-to-satellite communications. By exploiting its atmospheric absorption characteristics, the 60 GHz band, among others, is allocated for frequency sharing by ground and satellite-to-satellite operations.

The frequency bands above 66 GHz are allocated for the operation of mobile satellites and radio navigation satellites.

The 51.4~54.25 GHz, 58.2~59 GHz, and 64~65 GHz bands are allocated for earth prospecting satellites and space research. To prevent interference, emissions of any radio signals at these frequency bands are prohibited. The 61~61.5 GHz band is internationally allocated for industrial, scientific, and medical (ISM) equipment, and the band may be exploited with the approval of the government agency or agencies that have a vested interest in radio communications at that band.

At present, 50 GHz is allocated for use by propagation experimental stations, in addition to simple radios.

In the near future, the 50~70 GHz band is expected to be used in short-distance image and data transmission systems, image and data transmission systems in the especially large atmospheric absorption frequency bands, designed for use within a small compound or within a building, systems for searching for an object within a short radius (especially vehicular application) as part of the radiolocation operation, and systems for position locating within a short distance as part of the radio navigation operation. The use of simple radios in the already commercialized 50 GHz band is expected to expand.

(3) 70~100 GHz

Radio wave propagation characteristics within this region are that atmospheric absorption is relatively small and that the region is a window region for millimeter waves. The rain attenuation approaches a saturation with little dependence on frequency.

The frequency bands in this region are allocated for such operations as fixed communications, mobile communications, broadcasting, fixed satellites, traveling satellites, broadcasting satellites, and radiolocation.

The 86~90 GHz band is allocated for radio astronomy, earth prospecting satellites, and space research; emissions of all radio signals within this band are prohibited to prevent interference.

The band is at present used for propagation experiments by experimental stations.

Looking into the future, the 70~100 GHz region is expected to be used in such applications as short-distance image and data transmission, detection of approaching objects through radiolocation, crime prevention, weather radars, searching for objects, and small-area local broadcasting.

(4) 100~150 GHz

Radio wave propagation characteristics within this region are that atmospheric absorption increases as frequencies become higher and higher and that a small absorption peak is found in the vicinity of 120 GHz. tHe rain attenuation approaches a saturation with little dependence on frequency.

The frequency bands in this region are allocated for such operations as fixed communications, mobile communications, fixed satellites, traveling satellites, and radiolocation. Since 120 GHz and its vicinities can be easily shared with ground operations, the region is also allocated for use for satellite-to-satellite communications.

The 105~116 GHz band is allocated for radio astronomy, earth prospecting satellites, and space research; all radio signals are prohibited within this band to prevent interference. The 122~123 GHz band is internationally allocated for (ISM) equipment and may be used only with the approval of the agency or agencies that have a vested interest in radio communications in this band.

The band at present is used by the collimation experiment station. In the future, the band is expected to be used in such applications as short-distance image and data transmission, and as part of radiolocation operations that measure and search for objects.

(5) Above 150 GHz

In the studies, frequencies of about 140 GHz will be able to satisfy the demand for future millimeter wave systems described in paragraph 1.3.1. However, frequencies above 150 GHz are being considered in such applications as distance measuring and measuring of rainfall intensity. Therefore, this frequency band needs to be exploited.

Chapter 2. Current Status of Millimeter Wave Technology and Its Direction

This chapter describes the current status, problems, and direction of R&D on the fundamental millimeter wave technologies—such as the millimeter wave propagation characteristics, antennas, and millimeter wave circuit devices—needed to realize the millimeter wave systems listed in Chapter 1. Also discussed are problems awaiting solutions before the mentioned millimeter wave systems can be realized.

2.1 Characteristics of Millimeter Wave Propagation

Figure 2.1 shows attenuation of millimeter waves in space by atmospheric gases and rain. A propagation characteristic inherent with millimeter waves is that, because of their large attenuation as a result of their absorption by particles such as oxygen and vapor in the atmosphere and of their scattering by rain the waves cannot reach too far. If millimeter waves are to be incorporated in various systems, their attenuation characteristics at various frequencies and their scattering characteristics by objects need to be measured and understood.

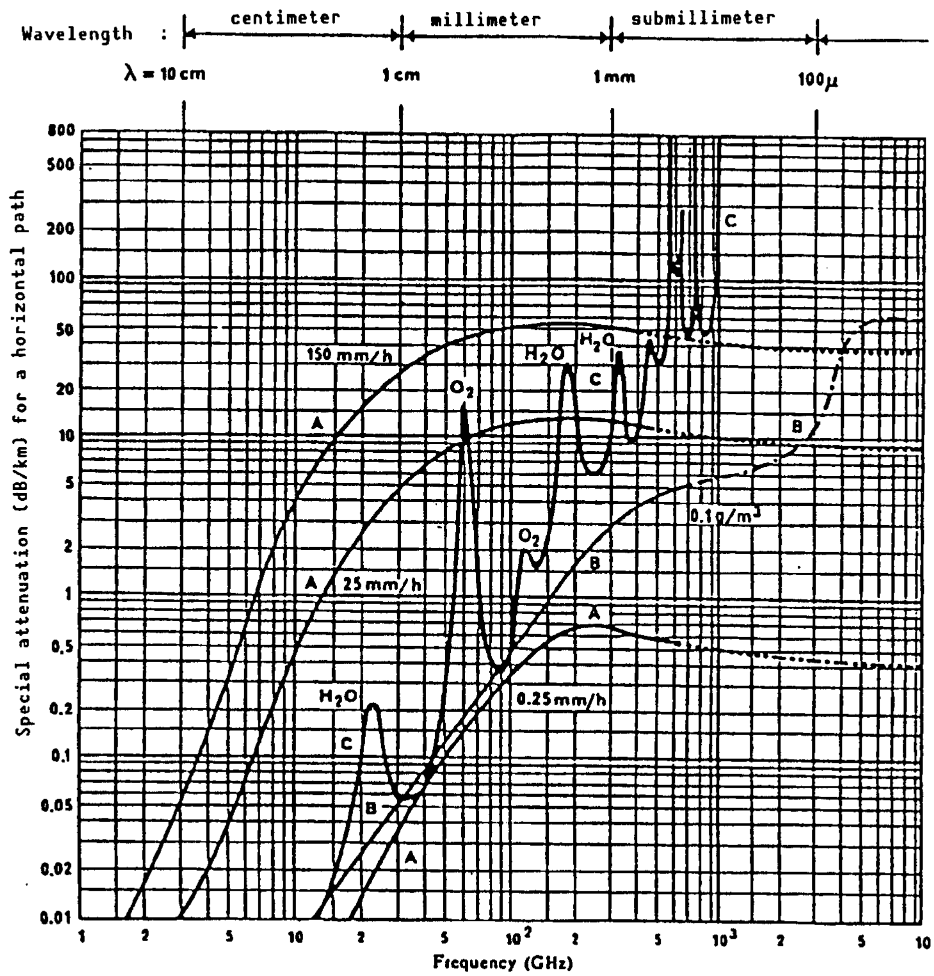
2.1.1 Absorption by Atmospheric Gases

It is known that in the high frequency regions, including the millimeter wave band, there exists a frequency band where absorption by atmospheric gas reaches a peak. For example, there are numerous absorption bands by oxygen particles in the vicinity of 60 GHz. The frequency band of a relatively small attenuation by absorption that exists in between these high absorption bands is the window region of the millimeter wave. However, in the frequency bands above 100 GHz the measured values of attenuation by absorption by vapor are far above the theoretic values of attenuation, which shows that attenuation is very large even in the window region.

The empirical formula that Liebe in the United States has derived from indoor experiments agrees well with the measured values, allowing accurate measurements of absorption by vapor at frequencies of interest. In practice, however, the formula recommended by the Advisory Committee on International Radio Communication (CCIR), is usually used for estimating absorption by vapor.

2.1.2 Attenuation by Rain

At frequencies in the millimeter wave's window region, signal attenuation by rain droplets has the greatest effect on propagation characteristics in the millimeter wave band. The statistics on the cumulative distribution of rainfall attenuation, the continuous time distribution, and the worst month distribution have been used for setting the rainfall margins for telecommunications circuits. It is also known that the amount of attenuation is strongly affected by the size of the rain droplet and the intensity of the rainfall. Detailed measurements have been taken to find out the relationship between rainfall attenuation and droplet diameter distribution, and it is now possible to make accurate estimates of the amounts of the rain attenuation for the entire millimeter wave region by using the rain attenuation coefficients



Temperature: 20°C	A: rain
Pressure: sea level: 1 atm	B: fog
Water vapor: 7.5 g/m^3	C: gaseous

Figure 2.1 Attenuation by Particles and Rain in Atmospheric Propagation

calculated using the CCIR model for droplet-diameter distribution, Marshall-Palmer mode, and the model developed by the Central Research Laboratories of the Ministry of Posts and Telecommunications. Figure 2.2 shows the characteristics of rain attenuation coefficient vs. frequency, based on the above raindrop diameter distribution models.

2.1.3 Scattering Characteristics

To solve such problems as multiple-bus trouble and interference found in various environments such as clusters of high-rise buildings or closed spaces, experiments on scattering characteristics at the millimeter wave band are needed using various ground objects or artificial structures. In addition R&D is needed on evaluation methods and suppression technology of scattering extraneous wave levels. Few scattering experiments at the millimeter wave band

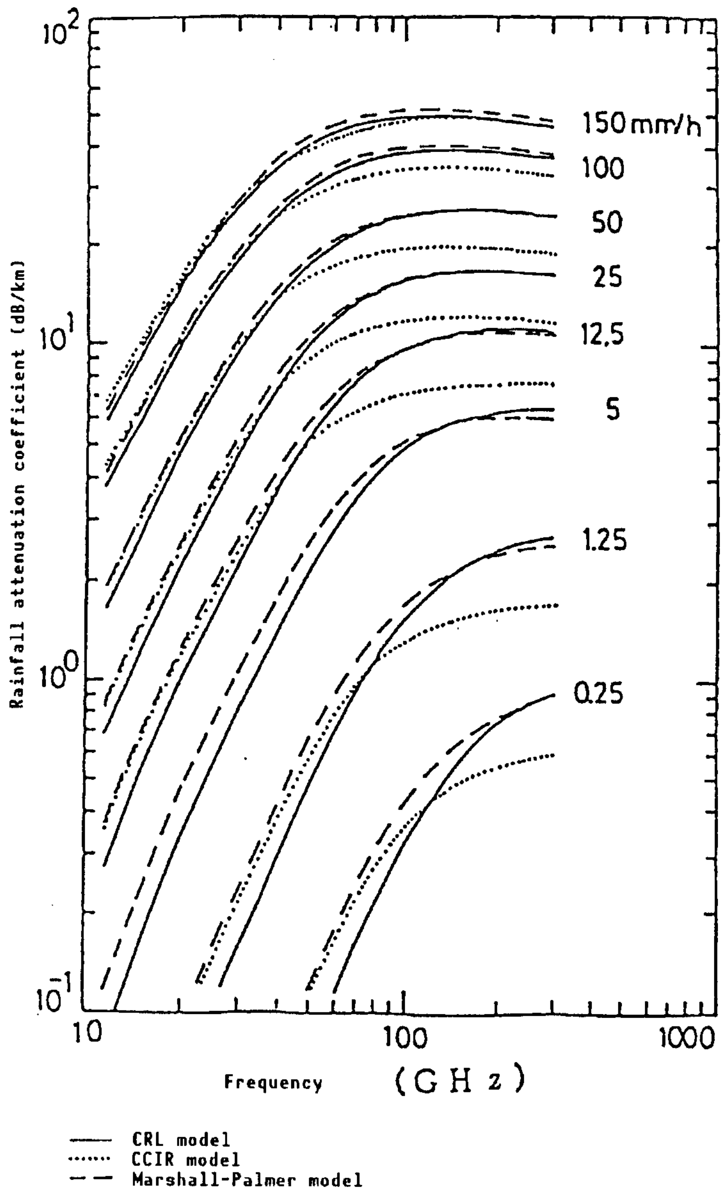


Figure 2.2 Frequency Characteristics of Rainfall Attenuation Coefficient

have been conducted worldwide, and Japan has just started gathering basic data and full-fledged experiments will have to be conducted in the future.

Along with these experiments, theoretical studies on scattering will also have to be promoted.

2.2 Current Status of Fundamental Technologies and R&D Movements

The systems described in Chapter 1 can be developed in the laboratory with existing technologies. However, before they can be widely applied as practical systems, problems with their fundamental technologies need to be resolved,

such as antennas and devices. Compared with systems used at other wave bands, the components of the millimeter wave systems are considerably more expensive, creating another obstacle to their widespread use. Thanks to advances in semiconductor technology in recent years, however, some difficult technical problems have been gradually overcome, which has laid the foundation for enhanced utilization of millimeter waves. The major R&D directions of the millimeter wave component technology as a whole at present are toward higher output power (electric field), higher frequencies, lower losses, lower noise, operational stability, and smaller and lighter weight configuration including monolithic structures.

2.2.1 Antennas

Antennas for use at millimeter wave band can be broadly classified into aperture surface antennas (horn, reflector, lens) that have such features as narrow beam width, low side lobe, and high gain, and array antennas that are used when small, lightweight antennas are wanted. R&D is also under way on the imaging array in which an antenna is combined with a detector.

(1) Horn Antenna

The most basic antenna for use at the millimeter wave band, the horn antenna features simplicity in structure, high efficiency, and a broad bandwidth, so it has been used widely by itself or as the primary radiator for other antennas.

(2) Reflector Antennas

Parabolic antennas and Cassegrain antennas are representative of this class of antennas, and are at present being used on the entire spectrum of the millimeter wave band. Parabolic antennas with an axially symmetric configuration are difficult to convert to low side lobe configurations because the arrangement blocks the primary radiator at the center. An offset parabolic antenna has been developed to eliminate these problems but the primary radiator needs to be developed to improve its crossover polarization discrimination. The Cassegrain antenna, a compound reflecting mirror antenna, has the advantage of small feeder loss, but further improvements will require development of a reflecting mirror material featuring low warping and of a dynamic mirror-face distortion-correction technique.

(3) Lens Antenna

An antenna incorporating a dielectric lens for converting a spherical or cylindrical radio wave into a plane wave is especially useful in high-frequencies. Featuring no aperture blocking and low side lobe, this antenna is widely used in radiators and various receivers.

Because it uses a lens, this type of antenna at present has problems with weight and weather resistance, and the signal loss caused by the material used to construct the antenna is also large. So, development of a low-loss material that can solve these problems is needed.

(4) Array Antenna

Arranging several radiating elements and through directivity synthesis can give the array antenna various capabilities, such as random gain control, side lobe control, and beam scanning. Especially when intended for use at the millimeter wave band, the array antenna can be manufactured as a small-size antenna, featuring a low side lobe characteristic. When used in applications that require high gains, such as satellite communication, however, as many as 3,000~5,000 devices need to be crammed into the antenna, and interconnecting them with waveguides makes the antenna extremely complex and expensive. Therefore, an array antenna using microstrip lines for feed is drawing attention as the direction of future R&D.

While microstrip array antennas have advantages of thin size, random configuration, and mass producibility, they have large feeder loss and require micro-working. In an attempt to solve the feeder loss problem, teflon fiber glass or crystal dielectrics have been used as low-loss substrate material, and, to prevent crosstalk caused by surface wave propagation on the substrate, the use of thin-film substrates or reverse-microscope lenses has been attempted. Simultaneously, R&D is needed on monolithic phased array antennas that try to attain low loss by shortening the wiring through incorporation of phase converters and low-noise amplifiers.

Let us here take up a satellite-borne antenna, for example, as a case study for a concrete application in which it will be necessary to carry out R&D on the following technologies in addition to the aforementioned fundamental technologies: 1) environment resistant technology; 2) storage/unfolding technology; 3) antenna beam forming technology; 4) antenna beam directivity control technology; 5) configuration control technology and technology for maintaining planarity accuracy; and 6) technology for reducing weight.

2.2.2 Millimeter Wave Circuit Elements

(1) Transmission Line

Conventionally, three-dimensional circuits made up of waveguides have been used, but they have problems with downsizing and mass producibility. Recent advances in semiconductor technology have improved circuit loss and power capacity, and as a result various dielectric wires and plane wires, such as microstrip line, suspended strip line, and fine line have come to be used at the millimeter wave band. All feature small size and low transmission loss, and will probably come to be used in monolithic circuits based on gallium arsenide (GaAs). Problems remain, however, including limitations on usable frequencies (around 100 GHz at present), downsizing, mass producibility, and conformity between devices and circuits, and R&D will have to be conducted to solve these problems.

(2) Bunched Wave Circuits

There are many kinds of combining waves, a technique for obtaining high output power by synthesizing outputs from several oscillators. Circuit-level

synthesizers are classified into those based on a resonance cavity and others. While the resonance cavity synthesizer has high efficiency, capacity to synthesize high frequencies, small size, and light weight, it has a small bandwidth, limit on the number of waves that can be synthesized, and is difficult to adjust. Nonresonance cavity synthesizers, on the other hand, have broad bandwidth synthesis capacity, ease of design and configuration, and high isolation between terminals, but they have problems with scaling up and low efficiency.

Chip synthesizers used for synthesizing outputs from semiconductor devices have been developed as impact avalanche transit time (IMPATT) diodes or field effect transistors (FET). The chip sizes diminish in the high-frequency region, and these synthesizers have problems with thermal mutual interference and impedance adjustments among device arrays.

Still another method is the spatial synthesis method, in which radio waves radiated from a phased array antenna are synthesized while controlling their phases, but this requires a high level of phase control technology. When a much larger synthesized output is reached, a combination of these methods may be employed to compensate for defects of the individual methods.

(3) Oscillators and Amplifiers

Oscillators and amplifiers for use at the millimeter wave band can be broadly classified into electron tubes and semiconductor devices. Because of the need for downsizing, light weight, and low power consumption, semiconductor devices are expected to form the mainstay in future millimeter wave systems, and accordingly R&D has been centered on semiconductor devices. However, electron tubes that have been used widely for a long time will continue to be used in applications that require high output power.

a. Electron tubes

Table 2.1 shows the current state of millimeter wave, high output power obtained by using electron tubes. The helix traveling wave tube (TWT) has a broad bandwidth, while the coupled cavity TWT has high output power; both types are widely used in communications and radars. The magnetron and the klystron both have average output power and lifetime but are relatively small and lightweight. The magnetron is said to be more efficient than the klystron. The gyrotron is used to obtain an ultrahigh output power. Among other tubes are the extended interaction oscillator (EIO), which has high output, small size, light weight, and long lifetime, and the backward wave oscillator (BWO), which has small size and light weight, and large modulation index.

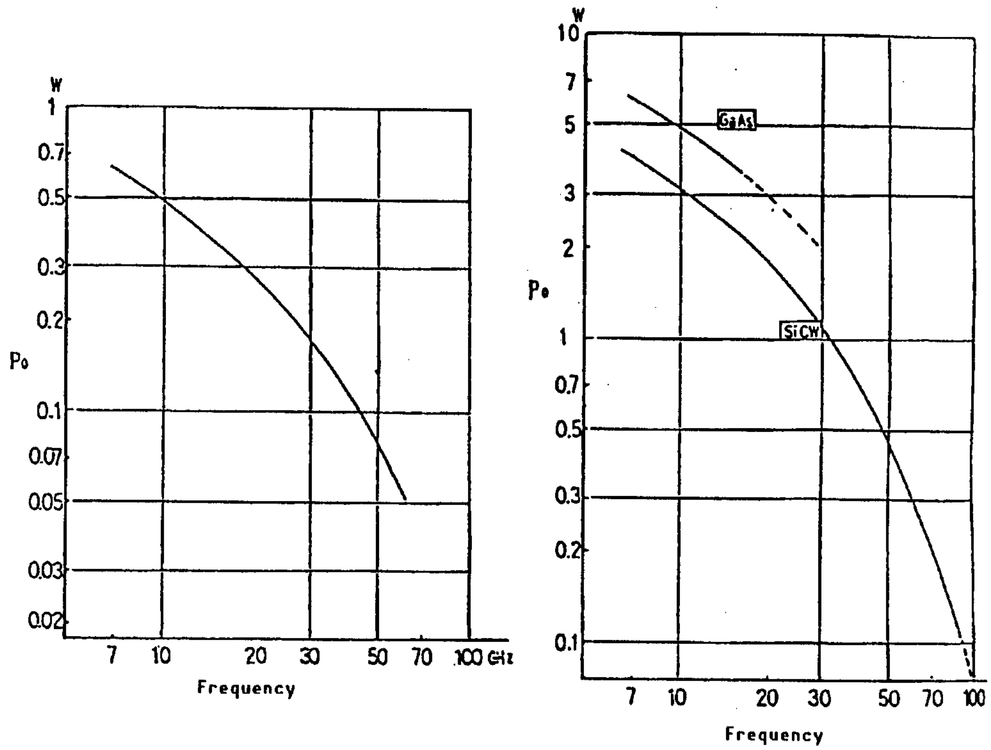
However, electron tubes generally have problems with probability and reliability, and when their configuration, weight, and efficiency are taken into account, their applications will be limited.

Table 2.1 Current Status of High Output Power of Millimeter Systems Based on Electron Tubes
(Source: Extracts from catalogues and data of major makers)

	Frequency	Output	Remarks
Extended interaction oscillator	50~ 80 80~ 110 110~ 140 140~ 170 170~ 300	35 W 25 W 10 W 5 W 1 W	CW
Grid controlled pulsed extended interaction oscillator	50~ 80 80~ 110 110~ 140 140~ 170 170~ 220	1 KW 1 KW 200 W 100 W 60 W	Pulse
Extended interaction amplifier	95 95	50 W 1000 W	CW Pulse
Reflex klystron oscillator	50~ 80 80~ 110 110~ 140 140~ 170 170~ 220	500 mW 300 mW 100 mW 50 mW 10 mW	CW
Klystron amplifier	30 35 45	500 W 4 KW 1 KW	CW Pulse Pulse
Coupled cavity traveling wave tube	35 95 30 45 80~ 100	50 KW 6 KW 2 KW 250 W 100 W	Pulse Pulse CW CW CW
Gyrotron oscillator	60~ 70 100 140 250	200 KW KW 1 MW 10 KW	CW CW Pulse Pulse
Backward wave oscillator	40~ 61 50~ 75 75~ 110 110~ 170	30 mW 50 mW 25 mW 20 mW	CW
Two cavity klystron oscillator	40 44	7 W 2 W	CW CW

b. Semiconductor devices

IMPATT and Gunn diodes have been most widely used, and their continuous oscillations at higher frequency bands have recently become possible. The silicone IMPATT, among others, holds great potential for higher output power and higher efficiency. Though inferior to the IMPATT in terms of output power and efficiency, the Gunn has better spectrum characteristics and lower noise, so it has been used in small output sensors and local oscillators. Indium phosphide (InP) or gallium arsenide has been used as the semiconductor material, but prospects are good that the InP Gunn can be used in higher frequency operations and with higher efficiency, so increased R&D efforts need to be made on the material. Figure 2.3 shows the characteristics of the millimeter wave diodes that have been developed in Japan.



(a) Gunn diode output power (b) IMPATT diode output power

Figure 2.3 Characteristics of Millimeter Wave Diodes
(Current state of development in Japan)

On the other hand, aggressive R&D has been promoted on three-terminal devices which, compared with two-terminal devices, feature ease of electric separation and enable simple circuits and their table operation. There have been rapid advances especially in the research on GaAs FETs, which is aimed at increasing output power and allowing operation at higher frequencies through such means as shortening the gate-length or air-bridge wiring, but these devices are considered to be near their performance limits. Therefore, more R&D is needed

on devices incorporating new materials and new structures, such as the indium phosphide metal insulator semiconductor FET (InP MISFET), which has a high cutoff frequency, high withstanding voltage, and large current; the high electron mobility transistor (HEMT); the heterojunction bipolar transistor (HBT); and the permeable base transistor (PBT) featuring low noise. Figure 2.4 shows the current state of three-terminal semiconductor oscillators.

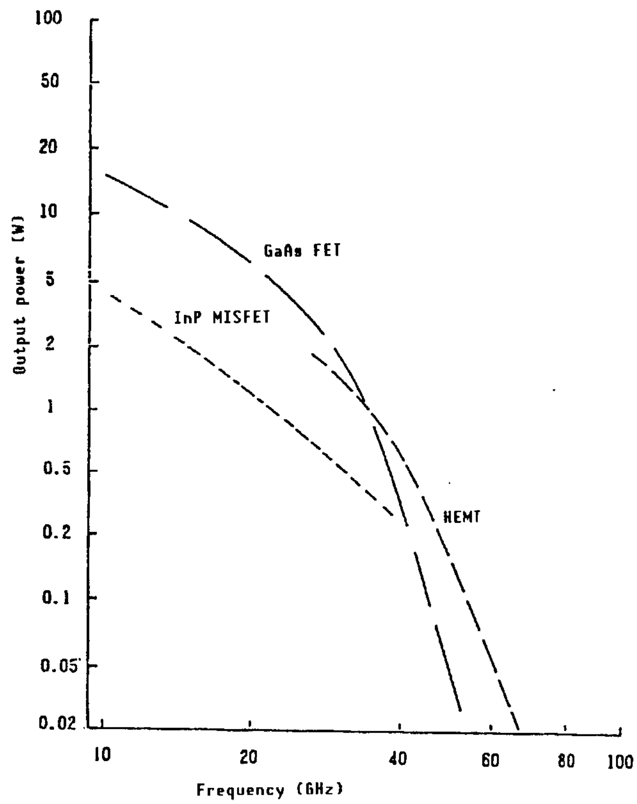


Figure 2.4 Current Status of Millimeter Wave Semiconductor Devices (three-terminal)

(4) Receiver Front-End Amplifiers

R&D efforts conventionally have centered on parameter amplifiers using two-terminal devices, such as Schottky barrier diodes (SBD) and tunnel diodes, but these are difficult to produce as small and lightweight products and have problems with electric power efficiency, stability, and reliability. Therefore, helped by recent advances in semiconductor technology, R&D has focused on amplifiers incorporating GaAs FETs for use in a broad spectrum from microwave to millimeter wave regions. Furthermore, the use of HEMTs will allow the noise level to be reduced still further. In extremely cold conditions, noise reduction of HEMTs is equal to that of parametric amplifiers, but limits their application is limited because they require large-scale refrigeration equipment. Consequently, R&D is needed on HEMT operations at higher frequencies and at lower noise levels under normal temperature.

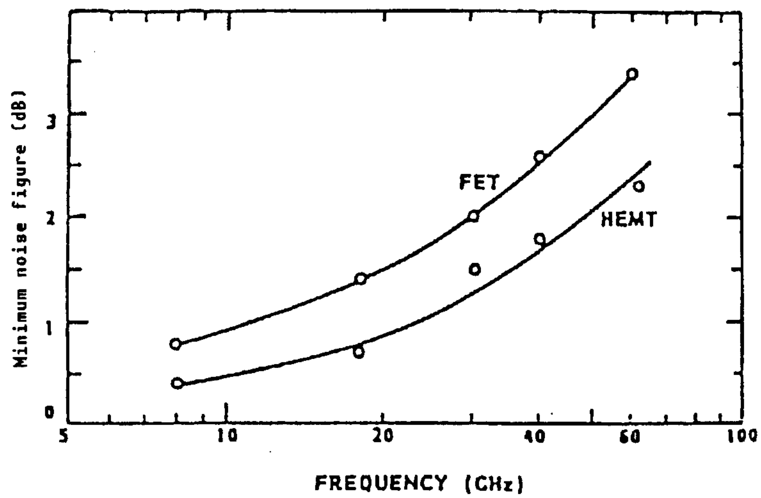


Figure 2.5 Comparison of Noise Indices for FET and HEMT at 0.25 μm

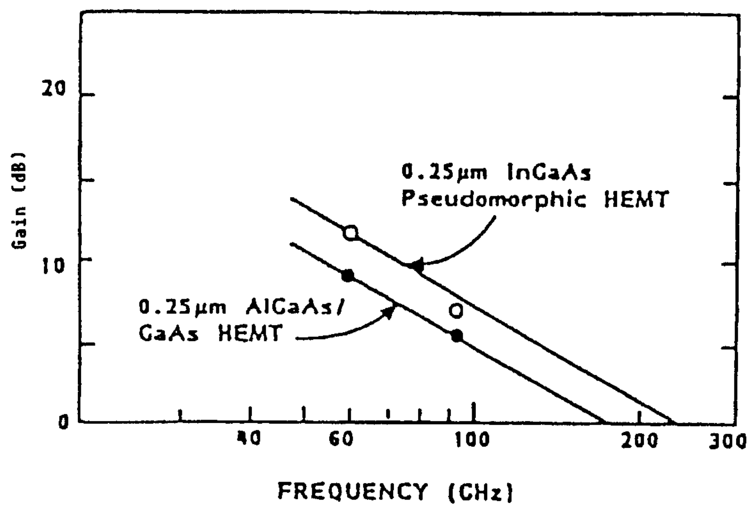
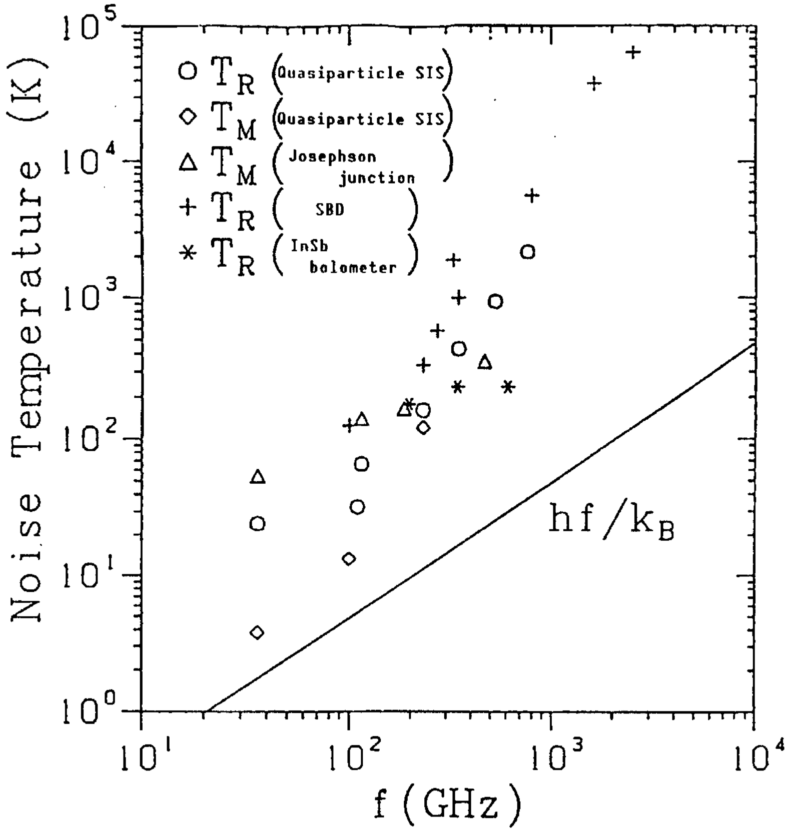


Figure 2.6 Comparison of Small Signal Gains for FET and HEMT at 0.25 μm

Figure 2.5 and Figure 2.6 show noise indices and small signal gains, respectively, for FETs and HEMTs with a gate length of 0.25 μm.

(5) Mixers

Figure 2.7 shows the noise characteristics of major devices found in the mixers used in the millimeter wave band. At present, mainly GaAs-based Schottky barrier diode (SBDs) are used. Among the mixer circuits mounted with SBDs are waveguide circuits, such as magic T, and the dielectric substrate circuits, such as suspended strip line. Compared with waveguide circuits, circuits based on dielectric substrates are better suited to mass production but at present do not perform as well because of the influences of loss in the dielectric substrate and parasitic reactance. Consequently, the two types of circuits have to be applied selectively. R&D to improve performance characteristics is needed.



T_R: Noise temperature of whole receiver
T_M: Noise temperature of mixer alone
Direct line: Theoretical limits of noise temperature

Figure 2.7 Noise Characteristics of Mixer

Mixers incorporating GaAs FETs having a conversion gain and capable of radio frequency amplification and HEMTs are also being increasingly used in the millimeter wave band, and continued R&D on their operation at higher frequencies is needed.

(6) Local Oscillators

The requirements demanded of local oscillators are basically the same as those demanded of oscillators and amplifiers, but frequency stabilities (time, temperature) and low noise characteristics are especially important. Output power high enough for practical use have yet to be attained in systems that demand additional capabilities, such as FM-CW radars and pulse doppler radars, and the deficits are being met with appropriate selection of frequencies, proper selection of the devices used, and the use of mixers that operate on a low local oscillator power.

Most conventional products are the waveguide type, but these have problems with assembly and adjustment and their machining accuracies are getting closer to the limits. Above 100 GHz at present, the Si IMPATT is advantageous, but in the actual cases the stepping output of the Gunn diodes or harmonic mixers are often used because of their spectrum characteristics and low noise features. At 50~100 GHz, the stepping output power of the low-noise GaAs Gunn is used, and at 30~50 GHz the stepping output power of the Gunn and the FET is used.

Among the major directions of development are: 1) high-frequency oscillations using three-terminal devices; 2) integration of two-terminal devices; and 3) low-frequency operation of mixers using the step function, R&D to increase mass producibility is also important.

(7) Dielectric Filters

Waveguide filters using a reactance window have been the mainstay until now, but millimeter wave band filters that are made of low-loss dielectric materials and that feature ease of fabrication, small size, and low-loss have come to be used in practical applications. Advances in the R&D of dielectric materials have been remarkable in recent years, and now materials with a Q of about 10,000 at 25 GHz have been developed. So R&D of materials that will enable realization of low-loss filters in millimeter wave band needs to be made. To attain even further miniaturization of circuits, dielectric filters of the microwave/millimeter wave integrated circuits (MICs) need to be developed.

Among the technologies that need to be developed are: 1) suppression of unnecessary modes; 2) maintenance of symmetry in transmission characteristics of broad bandwidth filters; 3) reduction of losses from the influences of the peripheral circuits, including input and output circuits and coupled circuits; and 4) establishment of the design theories for coupling between oscillators or between an oscillator and an input or an output device. For the development of dielectric filters, the machining accuracy of the oscillator needs to be increased, the temperature characteristics of the oscillator need to be improved, and the methods of adjusting the oscillator need to be established.

(8) Modular Construction

The costs of small, lightweight, yet highly complex millimeter wave circuits featuring high repeatability, high yield, and high reliability can be reduced through mass production but first will require high-density integration of circuits and their packaging in modules.

In the MIC (also called the "hybrid MIC")—a device in which active elements are mounted after forming microwave circuits on a dielectric substrate—alumina ceramic has been widely used as the dielectric substrate. MICs have had problems with parasitic reactances when the substrate circuits are connected, accuracy of patterning on the dielectric substrate, losses, and performance limitations arising from generation of high-dimensional modes. In addition, the thinness of the substrate limits the strength of the chip.

In the monolithic microwave/millimeter-wave integrated circuit (MMIC), integration is obtained by forming, on a GaAs substrate of about 0.15 mm, a buffer layer, activated layer, insulating layer, and metallic film in sequence. Compared with the waveguide circuit and the MIC, the MMIC at present has a larger circuit loss and limits on the electric power it can use, but it excels in terms of mass producibility, wide bandwidth characteristics, and size so is expected to find wide use in various applications. In the microwave band, an FET amplifier used as an MMIC has an output power much smaller than that obtainable with an amplifying circuit based on an FET per se, but above the millimeter wave band the MMIC may be able to obtain a higher output power than the FET.

Another problem with the MMIC is that as technology stands now, adjustments cannot be made after the circuits have been completed, so R&D is needed to improve the chip's performance by raising the uniformity of FETs through improved manufacturing processes or the introduction of HEMTs.

Throughout the 1980s, efforts have been made for packaging various circuits in modules, and, to reap the fruits of mass production, such modules have been incorporated in systems that are likely to find a large market. In the United States, a 6-year program to develop GaAs ICs called "microwave/millimeter wave monolithic integrated circuits (MIMIC) program" has been under way since 1986, and research is being promoted for the development of analog ICs that operate on frequencies above 2 GHz.

R&D efforts are needed in the following fields: 1) application of MMICs in the millimeter wave band by exploiting improved performance characteristics of semiconductor devices; 2) obtaining higher output power, higher efficiency, and higher frequency operation of modules by using new devices such as HEMT or by using new materials such as semiconductors of III-V group compounds other than GaAs; 3) high-speed and large-capacity subsystems fabricated by integrating high-speed digital ICs and optical electronic integrated circuits (OEICs), along with MMICs on a common GaAs substrate; and 4) introduction of computer aided design (CAD) technology in designing MMIC patterns.

(9) Future Technology

In promoting component technologies for millimeter waves in the future, R&D aimed at extending the existing technologies is necessary, of course, but R&D for new technological breakthroughs, such as application of various physical phenomena in millimeter wave elements, is highly important.

Active R&D efforts are under way on oscillator/amplifier elements and mixers based on superconducting materials. The superconductor-insulator-superconductor (SIS) mixer, for example, features low noise, small power consumption, and small size, and is thought to be operable in frequencies of about 300 GHz. Although slightly inferior to the SIS mixer in terms of noise characteristics, the Josephson mixer is considered operable on frequencies up to 600 GHz. At present, however, all superconducting devices require refrigeration and are made of unstable materials. So, increased R&D efforts are needed for solving these problems.

Research has recently begun on lasers based on quantum wells, and these are thought to have potential applications in oscillators/amplifiers and mixers operating on millimeter waves in the future.

Although the research on the application of such physical phenomena has just begun, the effort has the potential to elevate the performance of millimeter wave devices drastically in the future, so careful attention must be paid on the course of basic R&D in the future, and the achievements need to be used in actual applications.

2.3 Technical Tasks Associated With Utilization of Millimeter Waves

Using frequencies in millimeter wave band in discrete systems will generally result in the advantages of broad bandwidth capability and equipment miniaturization. However, to develop the system listed in paragraph 1.2 or to improve their performance, various tasks await solutions, in addition to those related to component technology described in paragraph 2.2. The major technical tasks that need to be researched and developed for each of the applications are described below.

Before any millimeter wave system can be widely applied, manufacturing costs must be reduced, in addition to developing the technical feasibilities.

2.3.1 Fixed Telecommunications

Millimeter waves are useful for broad bandwidth, short-range communications in places where laying of cables is difficult. Their bandwidth capability makes it easy to reinforce the error correction capability to ensure the quality of communications meets the user's expectation. Another great advantage is that millimeter waves make it possible to use miniaturized transmitter/receivers and antennas. Consequently, R&D needs to be promoted to exploit these advantages.

Circuit design must take into account that millimeter waves are highly vulnerable to attenuation by rain. The margin for attenuation by rain has to be set after taking into account the transmission length, the kind of transmission signal (image, analog telephone, or data), and such system parameters as the required nonoperating rate. The design of telecommunications circuits, which demand high-quality transmission, needs to be based on accurate radio wave propagation characteristics according to the nature of the transmission path, but a flexible network operation technology that addresses such factors as weather and the size of traffic has yet to be developed.

In urban areas, communications do not necessarily occur between two places along a line of sight, and even the line of sight for an established circuit may be obstructed by new buildings, making it necessary to install repeaters. Even when communications takes place between buildings, the transmission may suffer from multipath trouble or interference caused by proximity reflection of nearby buildings, so R&D is required on countermeasures, such as systems able to identify and suppress unnecessary waves.

The ISDN considered to be the future infrastructure is designed to transmit data at bit rates higher than the primary group interface (23B+D or 30B+D), so in setting circuits for the network many are counting heavily on using millimeter waves for broad bandwidth transmissions. To that end, R&D is needed on ISDN-compatible, millimeter wave receiver/transmitter systems by, for example, determining the interface conditions that can support functions demanded by the user and by developing MMICs that conform with the network.

Before millimeter waves can be used in CATV signal distribution systems, R&D needs to be made on channel arrangement methods and modulation methods that will facilitate efficient use of frequencies.

2.3.2 Mobile Telecommunications

Millimeter waves are expected to make broad bandwidth transmission of images and data possible, which cannot be done with conventional mobile communications using existing frequency bands. They will also make it possible to develop miniaturized receiver/transmitter equipment.

From a technical viewpoint, the narrow beam of millimeter waves has trouble tracking an object traveling at high speed. So, the technology that can catch and trace at high speeds the sharp beam of millimeter waves by using a phased array antenna needs to be developed, and a wide range of transmitting and receiving technology on the fixed side needs to be developed. Since millimeter waves propagate short distances, they will be used mainly in a minimum-zone system. Hence, in building a millimeter wave network, the technology for controlling the switching of transmission from zone needs to be developed.

Demand for multichannel, small bandwidth communications (voice, low-speed data, etc.), such as personal communications, is expected to increase in the future, and R&D will be needed on such areas as oscillation frequency stabilizing technology, high-level modulation/demodulation technology, and multichannel access (MCA) technology, which will make it possible to use frequencies in the millimeter wave band.

In mobile communications, the systems and equipment are generally used outdoors, so they must be weatherproof and able to withstand rain or snow. The shift to MMIC construction is essential, especially to build systems and equipment that are small and lightweight. If such high-precision machined devices are to perform under severe outdoor conditions, R&D will have to be made on packaging and temperature control technologies.

Furthermore, there will be technical problems trying to use millimeter waves in actual applications. In the case of a vehicle-mounted receiver system of traffic information, for example, technology will have to be developed that will enable the received images to be compressed efficiently and stored in internal memory, and the equipment will have to be exceedingly small, lightweight, and resistant to vibration. Again, to achieve broad bandwidth transmission the signal transmitted will have to be a high output power or the antenna beam focused sharply. Highly mobile systems—such as ITV cameras for use in construction, portable multiplex communications for disaster relief,

and wireless cameras—cannot carry a large-capacity power source, so efforts will have to be made to reduce its power consumption through such means as raising the efficiency of its oscillator while trying to increase its output power.

2.3.3 Telecommunications in Local Areas or Closed Spaces

When establishing communications circuits for high-speed and large-capacity intraoffice data transmission by linking OA systems and equipment or when transmitting images or data in a closed space such as an underground shopping mall or tunnel, the transmission probably will be affected by multipath as a result of proximity reflection. Therefore, the creation of an electric field that results when radio signals are emitted inside a room needs to be studied, and research is needed on the technology for coping with multipath creation and on systems that are least vulnerable to the effect of multipath creation.

2.3.4 Broadcasting

In building a small-area local broadcasting system, before the service area to be set efficiently, it is necessary to understand the radio wave propagation characteristics in the coverage area, such as an underground shopping mall or inside a tunnel, and then go ahead with forming the antenna pattern for transmission and other jobs.

2.3.5 Satellite Utilization

In a satellite communications system with a large number of personal terminals, the bandwidth per channel is not so large, but a greater number of users will increase the total bandwidths required. In data relays between ultrahigh-altitude platforms or in intersatellite communications, large amounts of data are transmitted, so efforts are made to use larger-bundle circuits, thus increasing the total number of the bandwidths required. As the capacities required have increased, the communications networks have had to be configured in a way that will afford effective utilization of frequencies, and development of technology for controlling the flow of data has come to be called for. R&D is also needed for simple, small, and cheap earth stations for use in personal satellite communications.

It is thought that satellite broadcasting at millimeter wave band will allow different broadcasting programs to be sent to different areas or the broadcast to be directed to some specific area, by taking advantage of the beam's sharp directivity. When a broadcasting operation is intended to cover the entire nation, on the other hand, the transmission power of the satellite needs to be increased. However, there is a limit on how much output power a TWT on board a satellite can get, and increasing the gains of ground station antennas to excessive degrees is not desirable because of installation costs. Consequently, the high gain of antenna and random directivity of beam need to be attained by the adoption of a multibeam, satellite-borne antenna.

Let us here consider a rainfall radar as an example of satellite-borne remote sensing using millimeter waves. The system will have to meet the following

conditions in terms of the distances that can be observed, the horizontal and vertical distance resolution, and the amounts of rainfall that can be observed (about 0.5~50 mm per hour). Given the limitations on the satellite's capacity (the amount of electric power that can be supplied, the amount of data that can be transmitted to the ground, and the weight and sizes of the machinery and equipment that can be carried), the system will have difficulty satisfying all of these conditions and trade-offs will have to be made if the system is to be operational. Millimeter waves will enable high-precision observation of targets that are not too far away but will make it harder to observe distant targets because of the inadequate output power and other limitations. As a result, millimeter wave observations will probably have to be supplemented with simultaneous microwave radar observations (two-frequency radar) to ensure their reliability.

2.3.6 Sensors and Radars

(1) Noncontact Card System

The use of millimeter waves will enable a remote target to be identified without coming into contact or will enable large amounts of data to be written or retrieved. When multiple targets are to be identified, the millimeter wave's narrow beam characteristics are very helpful in preventing signal interference.

If such a system is to be realized, many technical tasks need to be resolved. These include simultaneous identification of the target from among many other similar targets, detection of read errors and development of countermeasures to ensure the system's reliability, and development of integrated circuit cards capable of storing large amounts of information. When the system is to be used for identifying people, research will have to be made to determine whether radio wave radiation will have any adverse health affects.

(2) Vehicle-Mounted Sensing System

The millimeter wave's application in measuring distance between a car and an obstacle and the car's relative speed, the following technical tasks need to be overcome: the influence of the scattering reflection pattern, identification on a curved road, and elimination of interference with signals from other vehicles.

When millimeter waves are to be used in measuring a vehicle's speed relative to the ground, the following problems need to be solved: a drop in the responder's output power because of effects of mud, water, snow, etc.; interference with radio signals from other vehicles; changes in the reflection characteristics brought about by road surface conditions such as freezing, water pools, asphalt pavement, concrete pavement, etc.; and drops in the reflection electric power.

When detecting an obstacle under snow, the reflection characteristics vary depending on the quality of the snow and whether it is frozen or melting, so the technology needs to be developed that will allow reception and analysis of weak reflections from an obstacle buried under the snow.

(3) Obstacle Detection

Methods need to be developed that will elevate the detection limits for objects with small radar cross sections, for example, a helicopter-mounted warning sensor able to detect a power cable strung in the air.

(4) Measurement

Millimeter wave FM-CW radars are being considered for use in level gauges, water gauges, and snow meters. In increasing the accuracy of measurement (resolution), the greatest technical tasks are the broad bandwidth sweep and broad bandwidth operation of the millimeter wave transmitter/receiver system. A blast furnace insert profiler is basically a measurement of distance using an FM-CW radar, but the task there is how to process large measurement errors brought about by an unevenness of the surface of the object inside the furnace, and development of software is important.

(5) Radiometer, Thermography

The millimeter wave radiometer is already established as a system, and there is no specific technical task from the viewpoint of hardware but development of millimeter for data processing is important. With thermography in particular, detailed understanding of temperature characteristics of millimeter wave radiation from inside the body is necessary.

(5) Various Weather Observation Radars

Existing weather radars operate on the frequency least vulnerable to attenuation by rain (5.3 GHz) in order to observe phenomena in distant places. The millimeter wave radar is largely affected by attenuation by rain, but experiments on a cloud-measuring radar operating at 35 GHz have been under way for some time in an effort to develop it as a practical system. With millimeter weather radars expected to be realized in the future, research is needed for the development of a receiver capable of detecting weak radio wave reflections caused by raindrops and for a high-output power transmitter capable of observing a wide area.

A rainfall intensity meter is basically the same as systems being used in current millimeter wave propagation experiments. Raindrops sticking on the antenna mirror surface sometimes affect measurement even after the rain has stopped, such as attenuation, so a mechanism needs to be developed that will remove these raindrops. Since the measurement results are also affected by the raindrop size distribution, software-based data-correction technology is needed.

2.3.7 Use as Energy Source

For using millimeter waves as energy, R&D is needed on ways to increase the output power of the system as a whole; at the same time research needs to be made on the effect of radio wave radiation on humans. Measures to prevent the energy's spatial radiation from interfering with other signals need to be implemented, along with establishment of shielding technology.

Chapter 3. Measures for Promoting Use of Millimeter Waves and for Advancing R&D of Millimeter Waves

As described in Chapter 1, the use of millimeter wave band is expected to lead not only to new applications that have been difficult at frequencies below the microwave band, such as high-capacity mobile communications of images and data and high-precision sensors, but also to be used as an alternative to frequencies below the microwave band, where demand is expected to be tight in the future. Thus, millimeter wave systems are expected to play an important role in the highly advanced information-based society. The exploitation of the millimeter wave band would in turn form a market for new millimeter wave equipment.

From this point of view, the technologies listed in Chapter 2 are expected to be developed, but as of now they are not mature enough to find widespread practical application and, for the user, too expensive to be put to practical use. Conversely, equipment manufacturers cannot be certain whether the market for millimeter wave systems will develop to the point they could recover even their R&D investment, and, thus, many regard the industry as too risky a venture. All this hinders development of millimeter wave utilization, much like the old quandary of "Which comes first, the chicken or the egg?"

Like the period of 10 years or so ago when R&D was actively being made on millimeter wave waveguide transmission methods, the environment for millimeter wave development has been improving in recent years thanks to advances in semiconductor technology, which forms the basis for millimeter wave technology. For millimeter wave technology to find widespread application by extricating itself from the "chicken or egg" problem, its development needs to be targeted in the three stages of short-, medium-, and long-term phases, and policies described in paragraphs 3.1 and 3.2 need to be implemented.

(1) Short-Term Goal

For the short term, the goal should be to widen the use of existing systems, including fixed communications, mobile communications, and simple radio systems. This will raise effective utilization of millimeter waves in the 40~50 GHz band and reduce the costs of various components through mass production. Once this has been achieved, chances are that the costs of developing millimeter wave systems will greatly improve, giving rise to a fresh demand for new millimeter wave systems. All this would be seen as reducing development risk and development cost, thus ushering in a favorable cycle of "widespread use of systems lowering their manufacturing cost."

(2) Medium-Term Goal

The medium-term goal should be to extend existing systems, such as image transmissions between mobile units and fixed positions, and to commercialize R&D projects already under way, such as the collision prevention radar for cars and using millimeter waves in space communications.

This would greatly improve the prospects for expanding the practicable frequency bandwidth to bands above 60 GHz, for developing new millimeter wave components, and for further reducing costs of components.

(3) Long-Term Goals

Long-term goals should be directed toward using various millimeter wave systems to enhance livelihood of the people through and expand the use of frequencies up to and above 100 GHz. As things stand now, the basic technology for millimeter waves is beginning to take root, but R&D progress has been slow as the frequencies become higher and higher. Thus, to support the goal of developing various millimeter wave systems such as millimeter band ICs, concerted efforts need to be made for development of fundamental technology.

3.1 Measures for Promoting Utilization

3.1.1 Subsidies to Users of Millimeter Waves

At present, millimeter wave systems cost more than 10 times as much as microwave systems, which may be discouraging potential users from introducing them. The best way to overcome such a situation may be to focus the R&D effort on systems that are likely to generate a large demand and reduce their costs through mass production, which would pave the way for a smooth introduction of the subsequent systems. In light of the higher costs of introducing new millimeter wave systems, it is desired that the users of such systems be provided with subsidies, such as government financing or tax benefits.

3.1.2 Improving the Environment for Widespread Diffusal of Millimeter Wave Systems

(1) Existing Systems

To develop new applications of existing millimeter wave systems, flexibility in system design and system outline are a must in order to ferret out the latent demand for them and thus increase their widespread use.

One of the reasons the use of millimeter waves has been slow to develop is that the usefulness of millimeter wave systems has not been widely known. Therefore, it is important to promote public relations campaigns by demonstrating model millimeter wave systems in events or fairs.

(2) Future Systems

Among new millimeter wave systems under consideration are 1) systems that have large tolerances for interference depending on use and 2) systems that may be made easier to operate through the introduction of microprocessors. Judging from the physical nature of millimeter waves, millimeter wave systems are expected to be less affected by mutual interference at the absorption band of oxygen than smaller bands. The characteristics of millimeter waves may make it possible to develop systems that will technically allow a large number of users to receive the same advantages, such as on contact cards, for example.

Proper responses are expected to be made for these systems depending on the characteristics of the millimeter wave band and the mode of its use.

In setting technical standards, consideration will have to be given to efficient utilization of the limited availability of frequencies but consideration also needs to be paid to encouraging more widespread application of the systems.

3.2 Measures for Promoting R&D

3.2.1 Promoting R&D of Important Tasks

If millimeter wave systems are to be realized, the various technologies listed in Chapter 2 need to be researched and developed. To promote R&D efficiently, emphasis will have to be placed on basic technologies listed below, which are considered to be especially important and to have a high ripple effect.

(1) Millimeter Wave Band Propagation Characteristics Inside Offices

One of the promising uses of millimeter waves is in closed spaces such as offices and factories that are free from attenuation by rain. At present, however, radio wave propagation characteristics in such applications are not fully understood, so propagation characteristics of millimeter waves in closed spaces, including scattering and multipath of millimeter waves caused by walls, floors, ceilings, etc., need to be measured and basic data need to be compiled.

(2) MMIC Technology

To contribute to downsizing and mass production of millimeter wave systems, and hence to their widespread use, MMIC technology is needed for integrating millimeter wave circuits. Given the accumulation of semiconductor technology over years, Japan may be able to research and develop the technology in a relatively short period of time, followed by production of MMICs. To help widespread use of millimeter wave systems, R&D is needed for high-frequency and large electric power operation of MMICs, including the facilitation of circuit and layout design through the introduction of CAD.

(3) Millimeter Wave Band High Performance Antennas

Of the various antennas for use in millimeter wave band, one of the key technologies is the phased array antenna, which will make it possible to downsize millimeter wave transmitter/receiver equipment and to have random beam directivity. It can be used not only in mobile communications and satellite communications where a mobile object is tracked at high speed using a narrow beam at millimeter wave band, but also has potential for wider applications. For these applications to be realized, R&D is needed to develop the technology for low loss and micromachining of the components making up the phased array antenna and for the establishment of the beam's scanning and tracking technology.

3.2.2 Implementing the System for R&D Promotion

(1) Promotion of Cooperative Research by Academics, Industry and Government

None of the millimeter wave systems is expected to be in great demand for the immediate demand. As a result, R&D costs and risks are high, making R&D beyond the capacity of the private sector alone. Therefore, to spread R&D risks and hence to facilitate progress of R&D, a joint research system will be needed, especially in basic research, that will draw in the findings from universities, private companies, and government agencies. In implementing such a setup, pooling personnel and money in the key promoter of R&D would be effective.

For promotion of cooperative research, it may be a good idea to use existing public research organizations such as the Tsushin Sogo Kenkyu-Sho (Central Communications Laboratories) or to set up joint research organizations exclusively for research on millimeter waves.

(2) Promotion of International Joint Research

The potential of millimeter wave technology is also drawing attention in foreign countries and studies are under way on the use of millimeter waves. However, basic technology has not fully matured, and millimeter wave systems have yet to be used in ordinary applications. In promoting R&D of basic millimeter wave technology in the future, if only with the intent of reducing R&D risks and complementing each others' technological levels, international cooperation in research on basic technology needs to be promoted.

3.2.3 Establishment of an R&D Environment

(1) Subsidies to R&D Investment

In promoting R&D of millimeter waves, the availability of the system components or experimental systems and equipment is restricted, partly because of their high prices and partly because of the insufficient domestic manufacturing capabilities of such equipment. Furthermore, because of the risk of millimeter wave R&D as a viable commercial project and the project's questionable profitability, very little money has been available for investment in such R&D activity. One way to overcome such problems would be for public organizations to build or install those R&D facilities, equipment, and machinery and apparatuses considered to be of a high general-purpose utility and high importance and to make them available for use by the private sector. Also, financial and tax benefits would have to be offered for investment in R&D equipment by taking advantage of the institutional systems such as the Private Industrial Revitalization Law [a provisionary law concerning promotion of establishment of specific facilities by exploiting the capabilities of private enterprises] and tax shelters for high technology.

For basic R&D projects regarded as promoting millimeter wave utilization, it is important that the R&D support systems, such as financing by the Fundamental Technology Research Promotion Center, be exploited to the fullest.

(2) Promotion of Pioneering R&D Projects

The government's promotion of pioneering R&D projects, such as satellite communications experiments using millimeter waves, would not only lead to establishment of major technologies needed for the use of millimeter waves but will have a ripple effect on R&D of other millimeter wave systems. It is important that in the future such projects be planned for and increased research funding made available.

(3) Use of Frequencies With Due Consideration to R&D Activity

To facilitate the selection of frequencies to be used for research at an experimental station dedicated to R&D of millimeter waves, as well as to reduce the manufacturing costs of experimental apparatuses and equipment for use at a specific frequency band, it is important to consider ways to allocate several frequency bands for exclusive use for experiments in millimeter waves, in light of the systems' operations and the propagation characteristics of specific frequencies.

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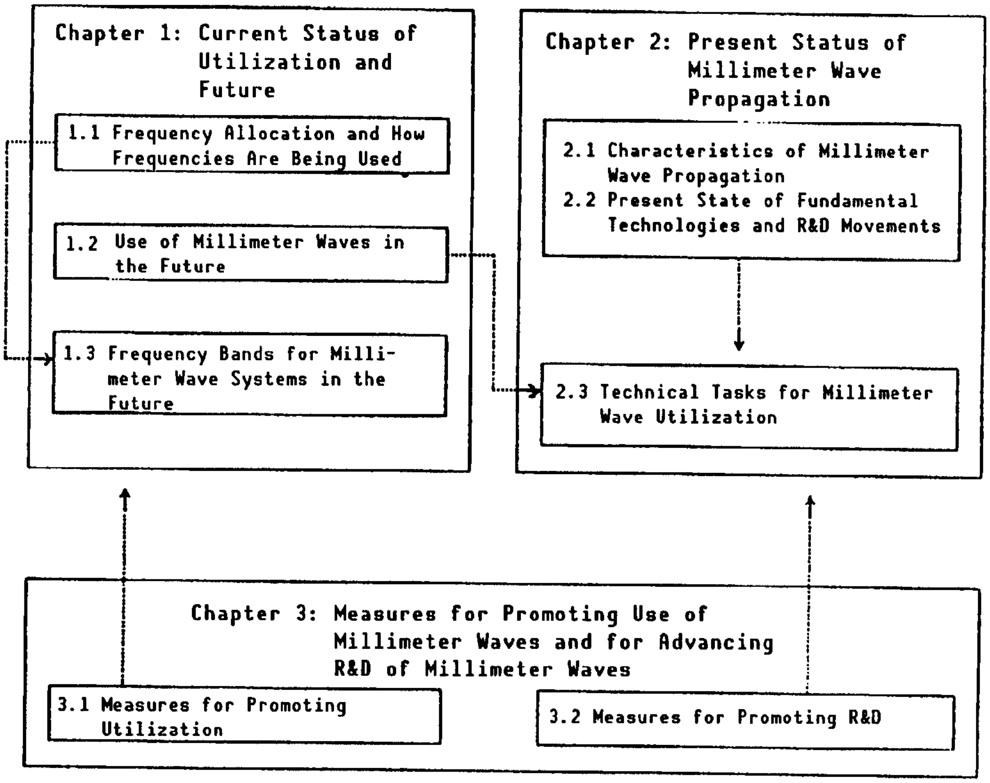


Reference Material 2 "Outlines of Future Millimeter Wave Systems"

Field/ division	Mode of use	Outline
Fixed communications		
High quality	Terminal circuits for broad bandwidth ISDN	When ISDN exchange is not available because of high cost of cable laying, networks based on millimeter wave can be built
	Terminal circuits for satellite communications channels	Instead of operating their own earth station, users can have access to common earth station through millimeter wave circuits
	Links for program broadcasting	Circuits as links for transmitting images and voice data between a studio and the satellite station
Simple	Short-distance fixed communications	Transmission of data between offices in close proximity, transmission of data and images to and from construction site or dam
	Cordless ITV camera	Use as a transmission section of ITV within a narrow range such as in a dam control office
	ITV system for monitoring urban traffic	Signals from large number of ITV cameras are transmitted to a repeater station where signals are received by vibrating antenna
	High-vision CATV	CATV programming is distributed to receivers' groups using millimeter waves
	CATV signal distribution system	Broad bandwidth CATV signal is distributed
Mobile communications		
Train	Transmission tunnel using satellite broadcasting	Using millimeter waves to transmit satellite broadcasting to inside tunnel where radio signal cannot reach
	Large-capacity transmission to and from trains (communications from station)	FAX service for train passing near a station with high-speed data transmission
	Large-capacity transmission to and from trains (communications throughout the rail system)	Transmission of voice information, data, and images between ground and trains to exchange control information
	Station platform monitoring system	Cameras transmit images of boarding and alighting passengers to the conductor

[continued]

[Continuation of Reference Material 1]

Field/ division	Mode of use	Outline
[Contd. Mobile communications]		
Train	Monitoring system for rail line and vicinity	Cameras installed at crossings and avalanche zones transmit images and/or warnings to the train
	Control of distance between trains	Distances between trains can be controlled to about 1 km by train-to-train communications
Automobile	Road-to-vehicle information communications/traffic information system (two-way)	Traffic information, position, destination guide, and area guide are transmitted to the driver
	Traffic information provision system (one-way)	Image and map information are transmitted to a car, which keeps necessary data in memory and shows it on display
Portable	Wireless ITV for construction work	Simultaneous monitoring of work stations in a large-scale project
	Short-distance FPU	To construct a circuit to a repeater car from a camera in a place accessible to cars
	Portable multiplex circuits for disaster relief	To establish telephone and image circuits between an accident/disaster site and a command post via satellite
	Binocular-type transceiver	Transmission while looking into another person's face. For use as a hobby.
	Broad bandwidth, small-zone mobile communications by leakage cable	Broad bandwidth communications using a card or a wristwatch-type terminal, radio wave reception by leakage cable
	Microcellular system	An ISDN-compatible portable terminal, communications are available anywhere
	Wristwatch telephone (small-zone system)	Communications system of low power consumption for use in extremely small zones
	Wireless camera (for broadcasting)	To construct multiple circuits from a camera in a place inaccessible to cable leading to a repeater car
	Wireless video monitor (for broadcasting)	Transmission of instructions to instruments in a TV studio, and transmission of movements within a room to a central monitoring office
	Remote monitoring-and-control system (for agriculture and civil engineering)	A remote monitoring-and-control system of unmanned units that move around autonomously within a 2-km range

[continued]

[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. of Mobile communications]		
Aircraft	Airborne power line monitoring system	To take images of cable supports, insulators, etc., with on-board camera and transmit to a control office
	Stratospheric communications	To connect mobile stations and fixed ground stations to each other using a mobile unit in the stratosphere as a repeater
Communications in closed space and tunnel		
	High-speed data communications network in a closed space	Transmission of information, including image data, to terminals for LAN and ISDN
	Two-way paging system for office use	Communications and display by designating room number and terminal number using a transmitter/receiver provided with a phased array antenna
	POS terminal communications system	High speed transmission of data from a POS or easily accessible terminal to a concentrator
	Vehicle control system	To exchange data on vehicle operation using a narrow beam from office and broad beams from vehicles in garage
	Mobile communications in underground shopping malls	Communications and liaison between mobile units in a tunnel or underground shopping mall or with the outside world
	Emergency communications in underground shopping malls	Emergency communications for contact (emergency telephone, ITV monitoring, various sensors)
Broadcasting		
	Small-area local broadcasting	Broadcasting information of community interest to a restricted area such as an underground shopping mall or a housing complex
Satellite Communications	Personal satellite communications system	Individuals have their own earth stations to communicate via a satellite
	Data relay between high-altitude platforms (HAPP)	Personal mobile communications using millimeter waves between HAPPs
	Intersatellite communication (ISL)	To construct circuits between a data relay satellite and observation satellite and/or a space station equipped with a gimbal antenna

[continued]

[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. Satellite]		
Communi-cations	Communications between space station and vicinity	A two-way communications between a space station and activities in the vicinity of the ship
Broad-casting	Satellite broadcasting	Satellite broadcasting at much more sophisticated levels than existing TV programming, such as high-definition TV, three-dimensional TV, beamed at individual areas
Radio naviga-tion	Satellite navigation system for use by private sector	Position locating using radio waves from two or three stationary satellites
Remote sensing	Observation of cloud thickness	Measuring thickness and kind (density) of a cloud using absorption of milli-meter waves by the cloud
	Satellite-borne rainfall radar	Measuring of rainfall over a broad area by using a satellite-borne rainfall radar
	Satellite-borne millimeter/submilli-meter wave radiometer	Observation of atmospheric environment from either a polar or geostationary orbit using a millimeter/submillimeter wave radiometer
Sensors/radars		
Non-contact card system	Millimeter wave ID system (for persons)	Used for controlling entries and exits of persons from room with capability of reading a noncontact card inside a pocket
	Millimeter wave ID system (for vehicles)	Used for identification and control of vehicles, control of vehicles in a garage, collection of fees, and discovery of stolen cars
	Millimeter wave ID system (for objects)	Used for control of physical distribu-tion and warehouses
	Noncontact ID card	High-speed transmission of large amounts of data by incorporating a millimeter wave oscillator in an IC card
Position recogni-tion/ object probing	Position recognition system	Detection of position and speed of cars and ships in a large-scale construction site or a large farm Used for unmanned operation

[continued]

[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. Sensors/radars]		
Position recognition/ object probing	Object search system	Recognition of position of multiple traveling objects in a natural environment and a garage. Used for surveying behavior of animals
	Airport surface search radar (ASDE)	To monitor movement of aircraft and vehicles inside an airport. Collision prevention, high-resolution radar
	Direction control system for digging machine	Direction of digging is controlled by receiving radio signal emitted from a reference point in back of digging machine
Obstacle detection/ collision prevention radars		
Car	Obstacle detection system for cars	To detect relative distance to and speed of a car or obstacle in front using an on-board radar and issue a warning
	Rear detection system for cars	Radar system capable of observing a car approaching from the rear (50 meters) when the operator is backing up his car or running ahead
	Radar for snowplows and road patrol cars	For detecting and displaying obstacles up to 100 meters away, such as front-running, oncoming or parked vehicles
	System for controlling distance from preceding car	For controlling distance between a car and one ahead, using an on-board radar to detect the relative distance and speed
Ship	Berthing system	For assisting a large ship get berthed by measuring the speed and distance during berthing
	Ship collision prevention radar	Monitoring movements of ships in narrow lanes, and displaying relative position and speed, and projected position
	Port monitoring system	A system to prevent ship collision and control by detecting the movements of ships in a port
Aircraft	Helicopter-borne collision warning sensor	Prevention of helicopter collisions by early detection of obstacles such as high-tension wires
	Helicopter landing aid system	Automation of control aids by measuring distance between helicopter's bottom and heliport and position by using millimeter waves

[continued]

[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. Sensors/radars Contd. Obstacle detection/collision prevention radars]		
Intruder detector	Intruder detection sensor (inside, outside)	Detection is made by exploiting Doppler effect of reflected waves from an intruder or intruding object and a warning is issued
	Radio wave fence (leakage cable method)	Detection of intruder in factory grounds or a railway yard
	Millimeter wave fence (reflection plate method)	Millimeter wave fence is put up around a nuclear power plant, etc., to detect intruders
Others	Car-to-ground speed sensor	Radar signal is emitted onto ground from car and car's speed is determined by Doppler effect
	Sensor for detecting road surface condition for cars	Radio signal is emitted onto ground from car to ascertain road surface conditions, such as freezing or wet, and speed is controlled accordingly
	Sensor for profiling road surface	Radio signal is emitted onto surface in front of a car, contour of road surface is detected to control vehicle speed and suspension
	Radar speedometer for speed violation control	Speed is detected by exploiting Doppler effect. Systems come in stationary and mounted versions and some are equipped with a camera
	Inspection of personal belongings including nonmetals	Shape and position of personal belongings are detected by reflected waves that come through clothing
	Landslide detection radar	Reflectors are installed at required places and inclination of each place is detected from the reflected signal
	Water gauge (rivers, dams)	Sensors are installed on both banks of a river and water level is measured from an angle
	Level gauge (tanks)	Weighing machine for oil in tanks
	Snowfall meter	Sensors are installed at two points and amount of snowfall is measured from an angle
	Wave observation radar	Height, cycle, and direction of waves are measured from ground
	Measurement of amount of water flowing in a pipe	When a flow meter is obstructed by an obstacle near it, measurement can be taken at a point away from flow meter. Amounts of diverted water can also be measured.

[continued]

[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. Other]		
	Power flow meter	Measurement of amount of powder being carried by a gas
	Moisture meter	Measurement of moisture in dielectric bodies (paper, oils)
	Vapor measuring system, VI meter	Measurement of vapor by exploiting propagation characteristics
	Fire detector, oxygen density meter	Transmissivity meter for use in tunnels
	Measurement of specular accuracy of reflector	Specular accuracy can be measured by emitting a millimeter wave signal at an object and comparing reference antenna and amplitude phases
	Measurement of thickness of steel plate	Measurement of shape and thickness of steel plate
	Thermometer for metal plate	Thermometer for use in situations where state of oxidation is not stable and emissivity changes
	Measurement of in vitro temperature (millimeter wave thermography)	By receiving radio waves in millimeter wave band emitted from a living organism, the temperature of the layer beneath the skin can be measured without touching the skin
	Measuring instrument of partial pressure of oxygen in blood	By heating a living organism using millimeter waves, the amount of oxygen is measured by sensor attached to the surface of the body
	Blast furnace insert profiler	By using millimeter waves, measurements are taken of several points to develop a profile of the insert
	Probing for buried pipes	Probes for objects buried underneath a road, checks for pavement defects, and probes for objects inside concrete structures
	Geological survey sensor	To measure underground formations by measuring time needed for radio wave emitted at ground surface to return as a reflected wave and by measuring the scattering of the reflected wave
	Radio wave/sonic wave radar (RASS radar)	Pulse radar/sonic wave emitter allows measurement of temperature distribution of fire and atmosphere inside blast furnace
	Measurement of nuclear fusion plasma	Measurement of electron density and temperature

[continued]

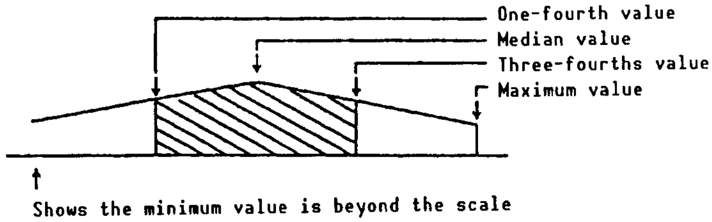
[Continuation of Reference Material 2]

Field/ division	Mode of use	Outline
[Contd. Other]		
	Rainfall density meter	By installing sensors at two points several hundred meters apart, intensity of rainfall is measured from radio wave's attenuation
	Weather radar	Measurement of rainfall intensity, clouds and fog
	Aircraft-borne rain area scattering meter	Aircraft-borne weather radar that measures three-dimensional distribution of rain intensity
	Air turbulence detector	Based on a radiometer method, it detects turbulence from temperature changes at absorption band by oxygen
Use as energy		
	Electron XEHXY resonance heating equipment	Used for igniting and heating plasma in magnetic field, containment-type nuclear fusion equipment, as well as for driving high-frequency current
	Millimeter wave electric power transmission system	Transmission of millimeter wave power for the electron cyclotron heating device in nuclear fusion equipment
	Hyperthermia	Heating of scattered cancer cells from outside the body

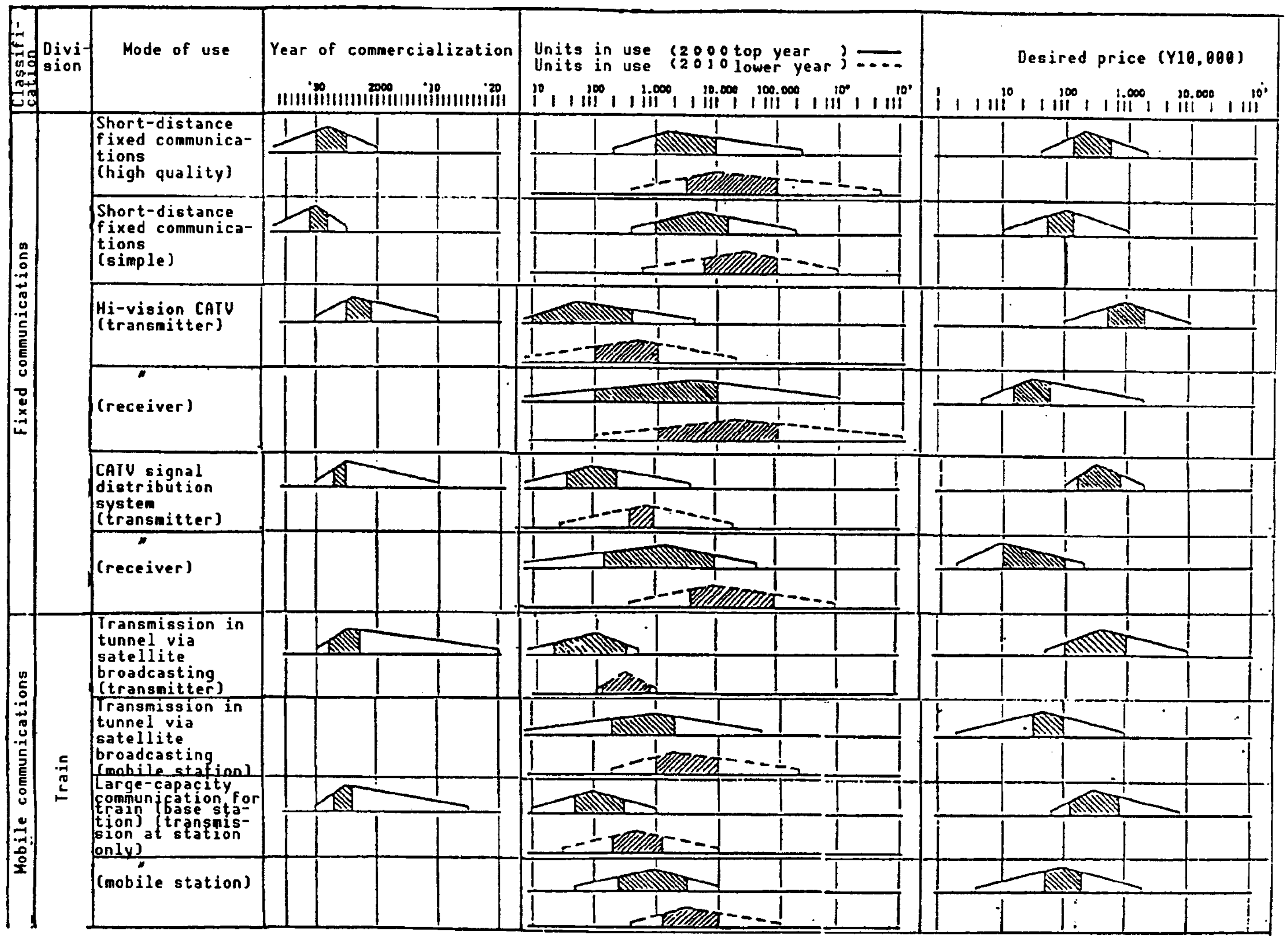
Reference Material 3 "Survey on Millimeter Wave Systems as to Timing of Commercialization, Number of Systems in Use, and Desired Prices"

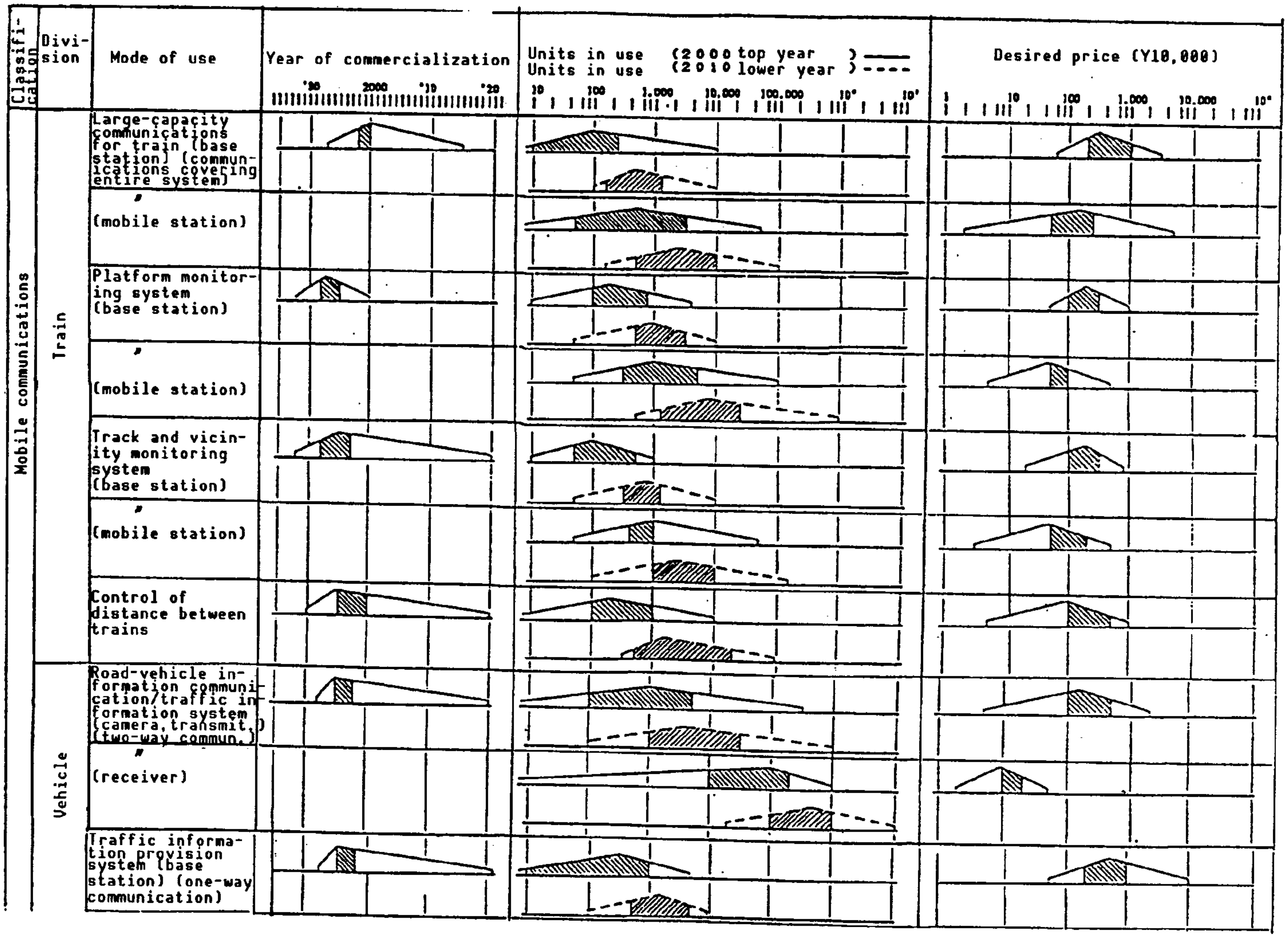
This material is a compilation of the results of a questionnaire using the Delphi method. In this survey, informed persons, including members of the Millimeter Utilization Subcommittee of the Millimeter Wave Utilization Technology Committee, were asked questions on when future millimeter wave systems will be realized as practical systems, how many of them will be in use (in 2000 and 2010), and what are their desired prices (from the users' perspective).

For each system, the results of the tally are shown as given in the diagram below. The diagram contains the scope of results of the questionnaire (the largest value and the smallest value), the median value, the one-fourth value (meaning the reply at the one-fourth place, counting from the bottom, of the total replies obtained), and the three-fourths value. However, in cases where the results of the questionnaire survey are beyond the scope of the scale, the maximum value and the minimum value are not shown, and only an indication is given that the results are beyond the scale.

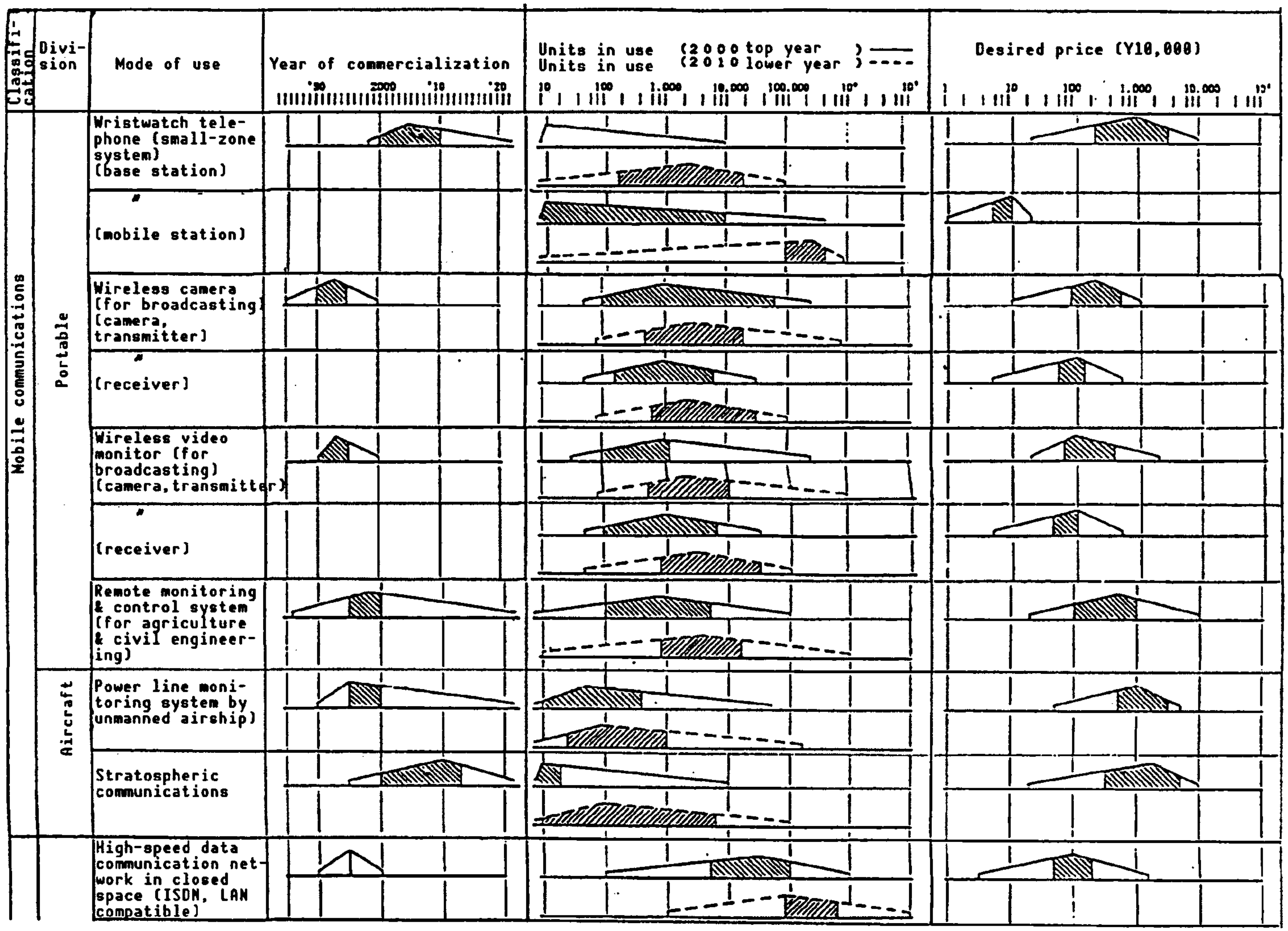


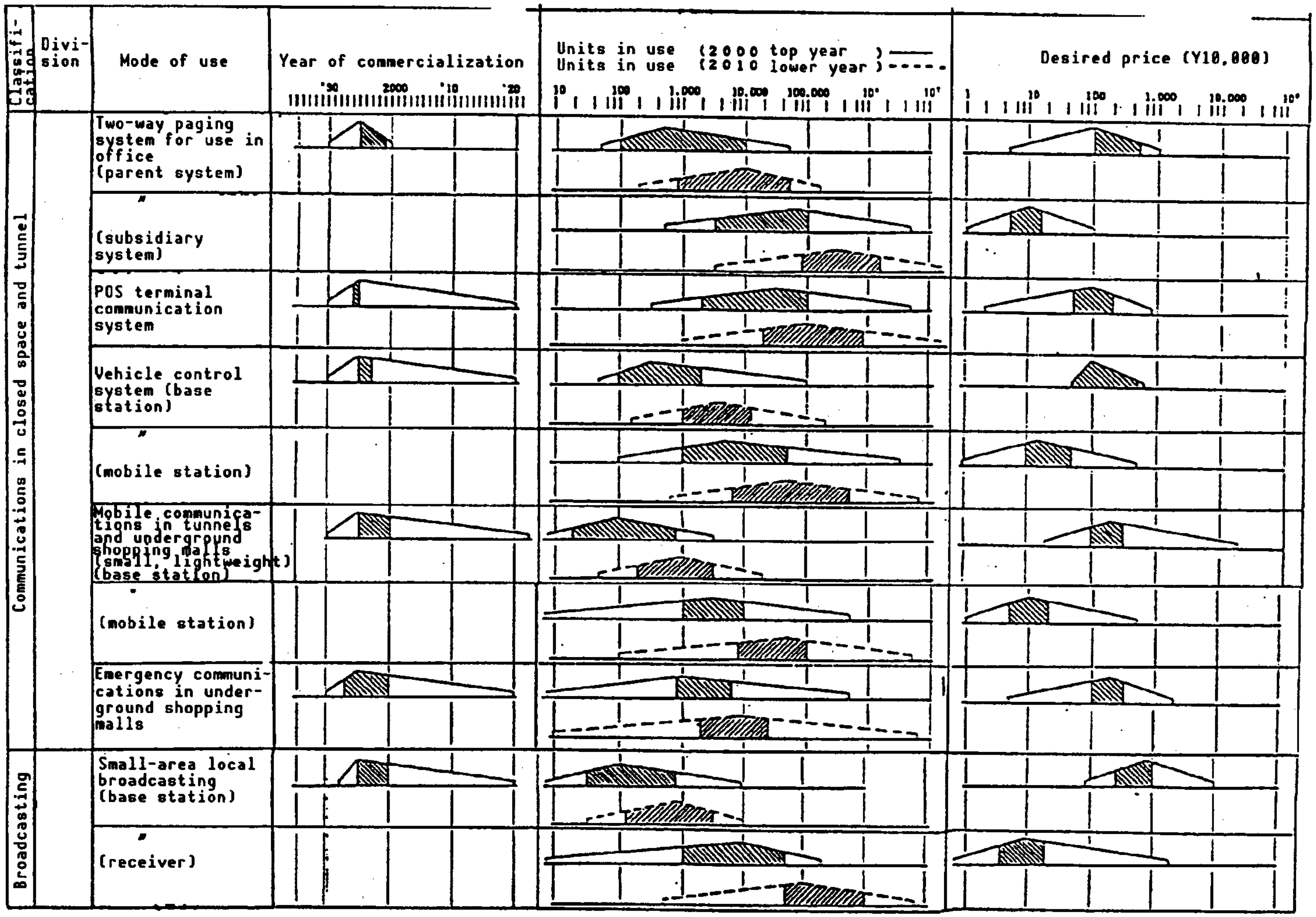
Based on the results of the survey and after taking into account the systems' lifetimes (the Ministry of Finance ordinance pertaining to lifetimes of depreciable properties was used for reference), the value of per-year demand for each of the millimeter systems was calculated for the years 2000 and 2010. To be specific, the timing of commercialization of each system, the number of units of the system in use in 2000 and 2010, and the system's lifetime were calculated first. Then, using these values, the demand for units of the system was calculated for each of the years, and the number of the units demanded was multiplied by the system's desired price to calculate the values of the demand for the system in 2000 and 2010. The totals for various systems were compiled, and the resulting value represented the total demand for the millimeter wave systems in the respective year. When the median values are used as representing the timing of commercialization, the number of units in use and the desired price, the total demand is ¥40 billion in 2000 and ¥200 billion in 2010. When the three-fourths value is used as representing the number of units in use while the median values are used for the other categories, the total demand is ¥200 billion in 2000 and ¥1 trillion in 2010.


Classifi-cation
Divi-sion
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year) ——
Units in use (2010 lower year) ----
10 100 1,000 10,000 100,000 10⁶ 10⁷
Desired price (Y10,000)
1 10 100 1,000 10,000 10⁵
Fixed communications
Short-distance fixed communications (high quality)
Short-distance fixed communications (simple)
Hi-vision CATV (transmitter)
" (receiver)
CATV signal distribution system (transmitter)
" (receiver)
Mobile communications
Train
Transmission in tunnel via satellite broadcasting (transmitter)
Transmission in tunnel via satellite broadcasting (mobile station)
Large-capacity communication for train (base station) (transmission at station only)
" (mobile station)

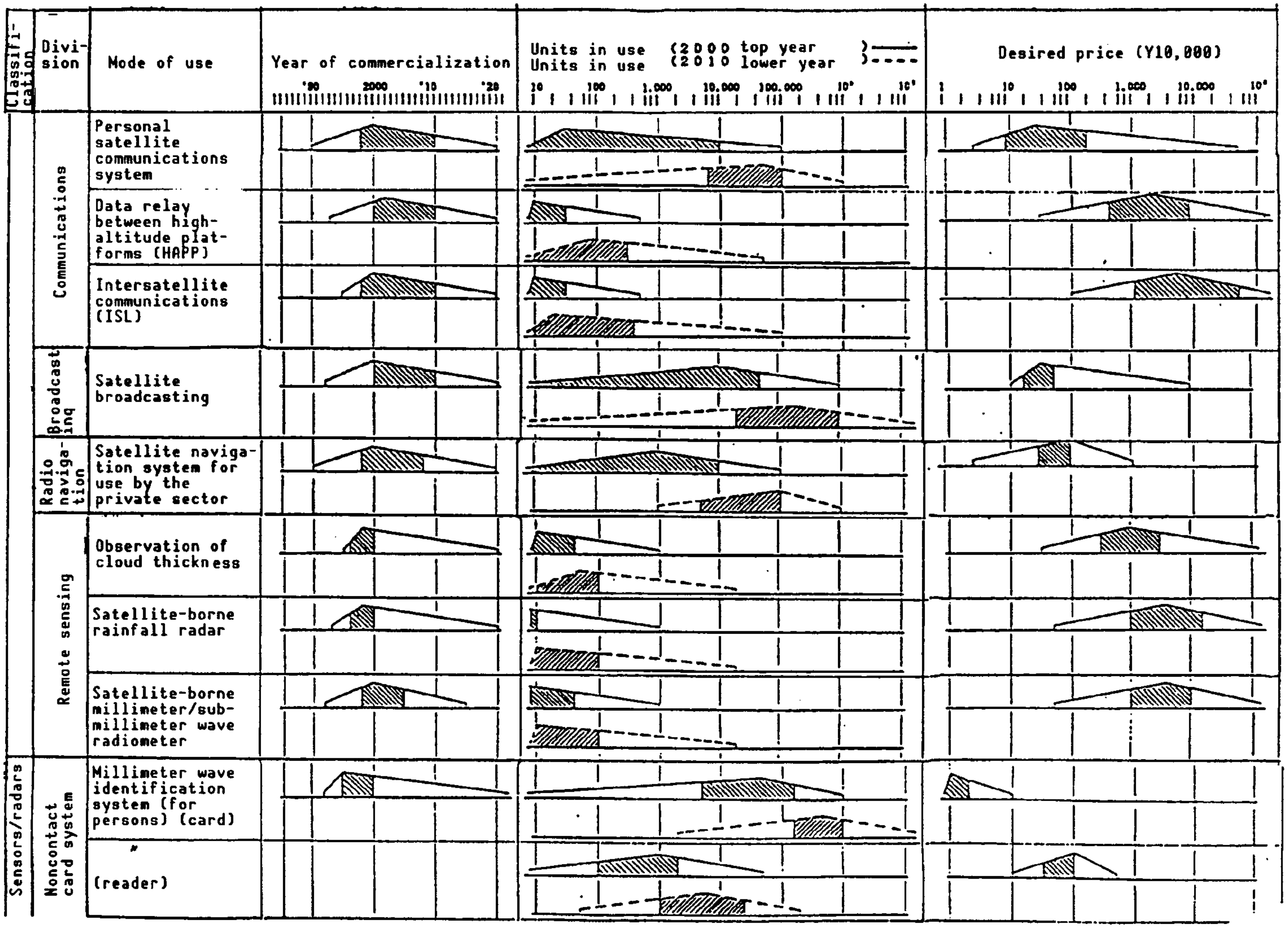

Classification
Division
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year) ——
Units in use (2010 lower year) ----
10 100 1,000 10,000 100,000 10⁶ 10⁷
Desired price (Y10,000)
1 10 100 1,000 10,000 10⁵
Mobile communications
Train
Large-capacity communications for train (base station) (communications covering entire system)
〃 (mobile station)
Platform monitoring system (base station)
〃 (mobile station)
Track and vicinity monitoring system (base station)
〃 (mobile station)
Control of distance between trains
Vehicle
Road-vehicle information communication/traffic information system (camera, transmit.) (two-way commun.)
〃 (receiver)
Traffic information provision system (base station) (one-way communication)

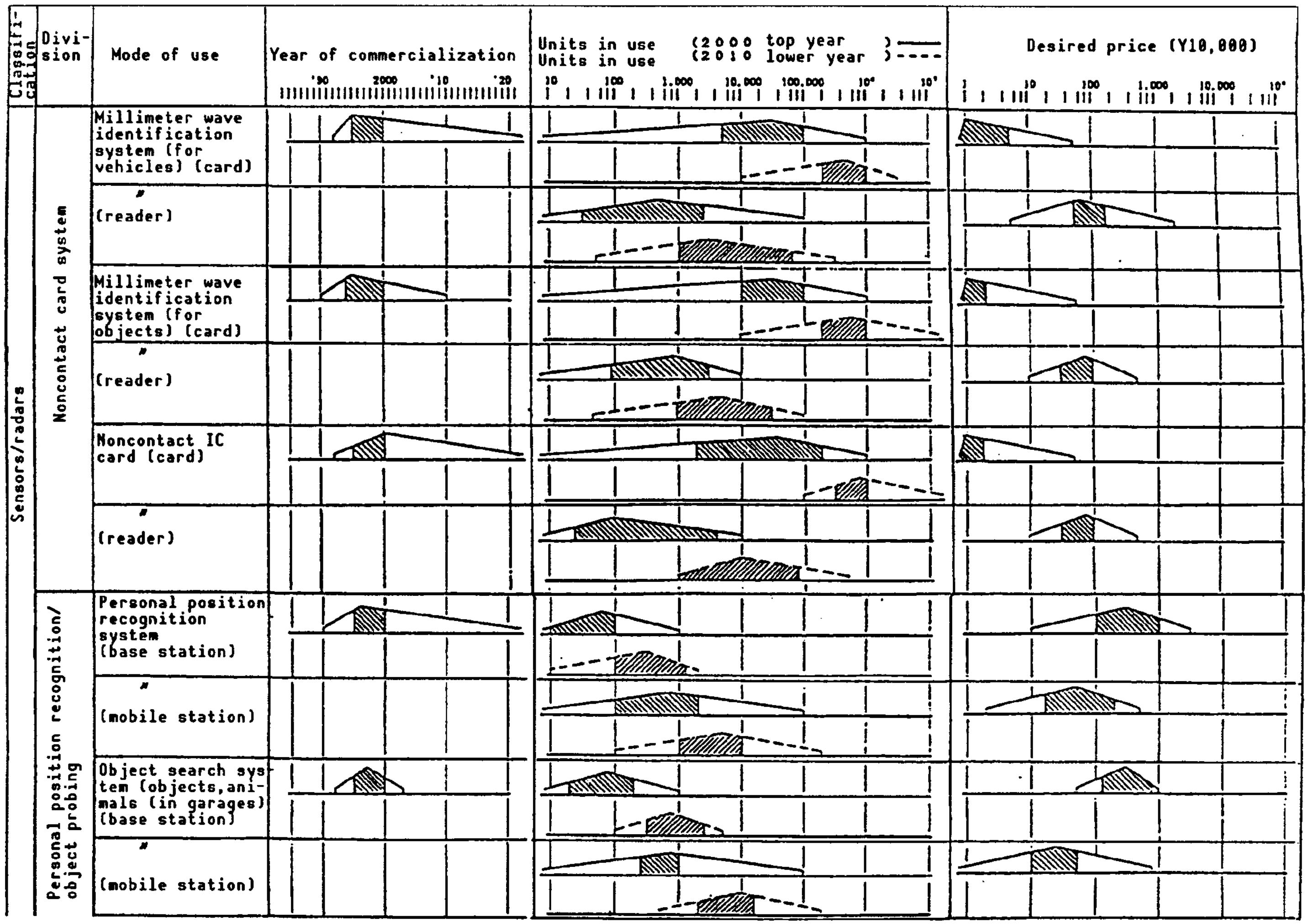
Classification	Division	Mode of use	Year of commercialization ('90 2000 '10 '20)	Units in use (2000 top year) —— Units in use (2010 lower year) ---- (10 100 1,000 10,000 100,000 10^6 10^7)	Desired price (Y10,000) (1 10 100 1,000 10,000 10^5)
Mobile communications	Vehicle	〃 (receiver)			
	Portable	Wireless ITV for construction work (camera, transmitter)			
		〃 (receiver			
		Short-distance FPU			
		Portable multiplex circuit for disaster relief			
		Binocular-type transceiver			
		Broadband, small-zone mobile communication by leakage cable (cable)			
		〃 (mobile station)			
		Microcellular system (compatible with ISDN) (earth station)			
		〃 (mobile station)			

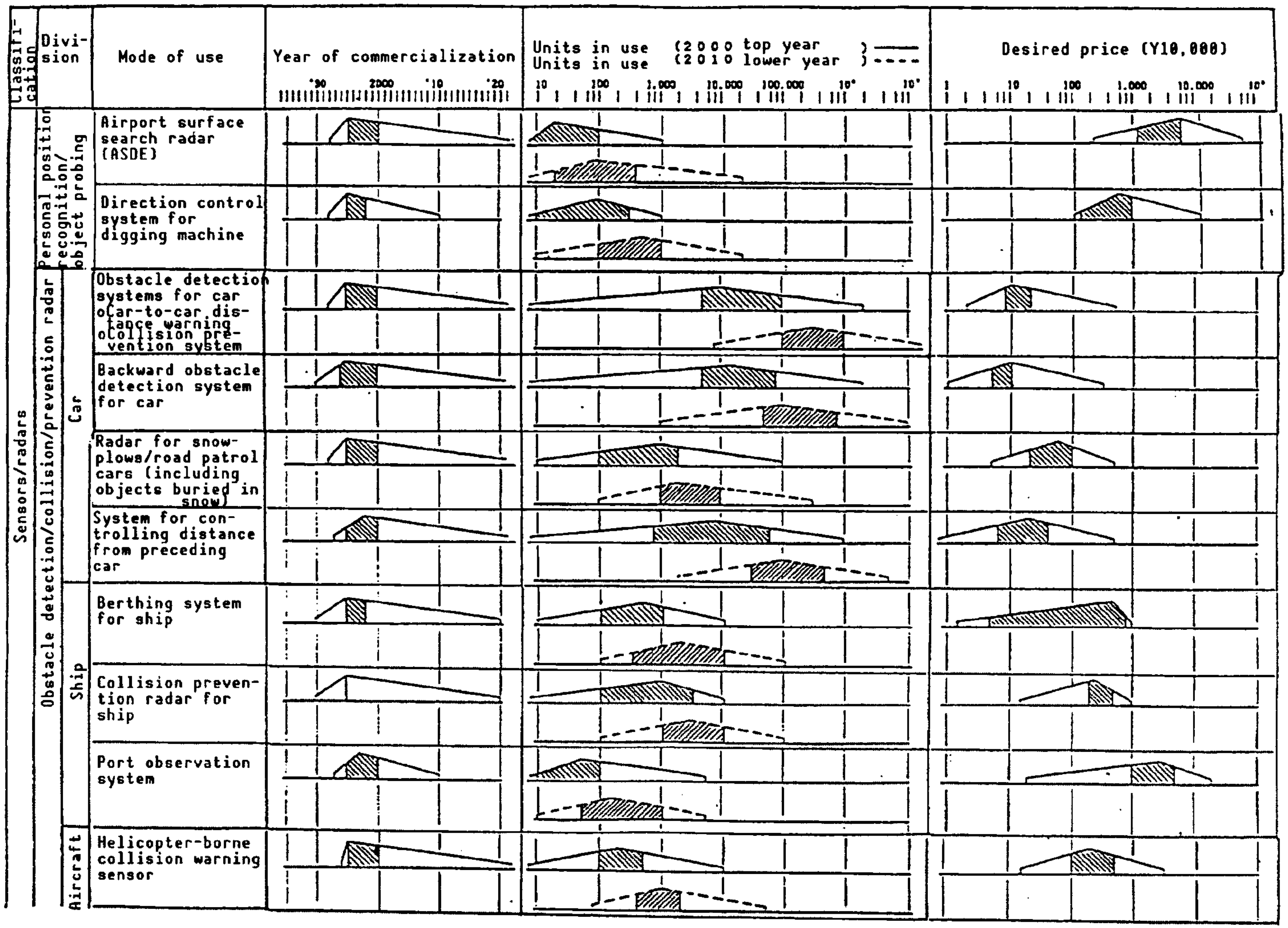

Classification
Division
Mode of use
Year of commercialization
'90
2000
'10
'20
Units in use (2000 top year)
Units in use (2010 lower year)
10
100
1,000
10,000
100,000
Desired price (Y10,000)
1
10
100
1,000
10,000
Mobile communications
Portable
Wristwatch telephone (small-zone system) (base station)
" (mobile station)
Wireless camera (for broadcasting) (camera, transmitter)
" (receiver)
Wireless video monitor (for broadcasting) (camera, transmitter)
" (receiver)
Remote monitoring & control system (for agriculture & civil engineering)
Aircraft
Power line monitoring system by unmanned airship)
Stratospheric communications
High-speed data communication network in closed space (ISDN, LAN compatible)

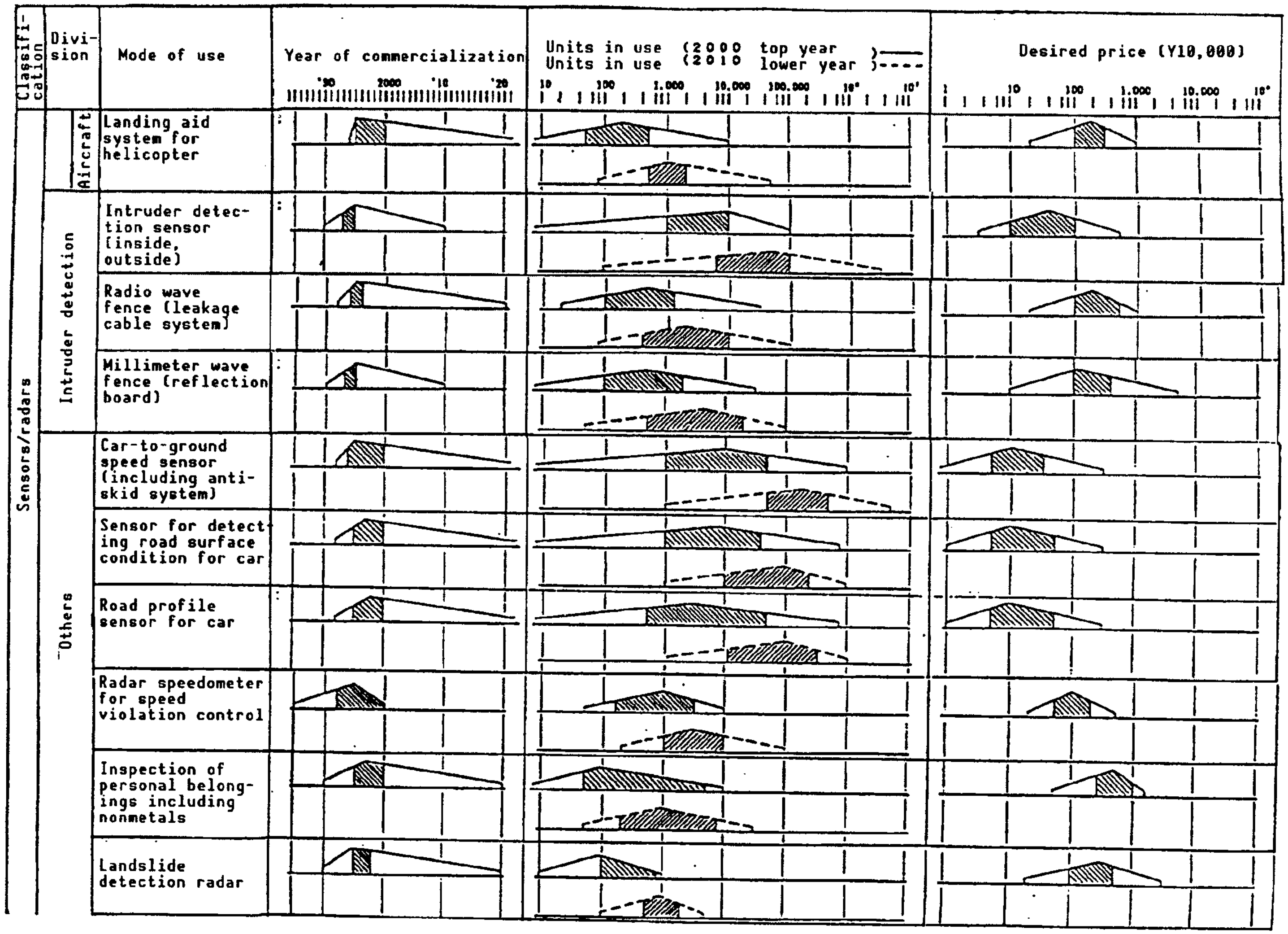


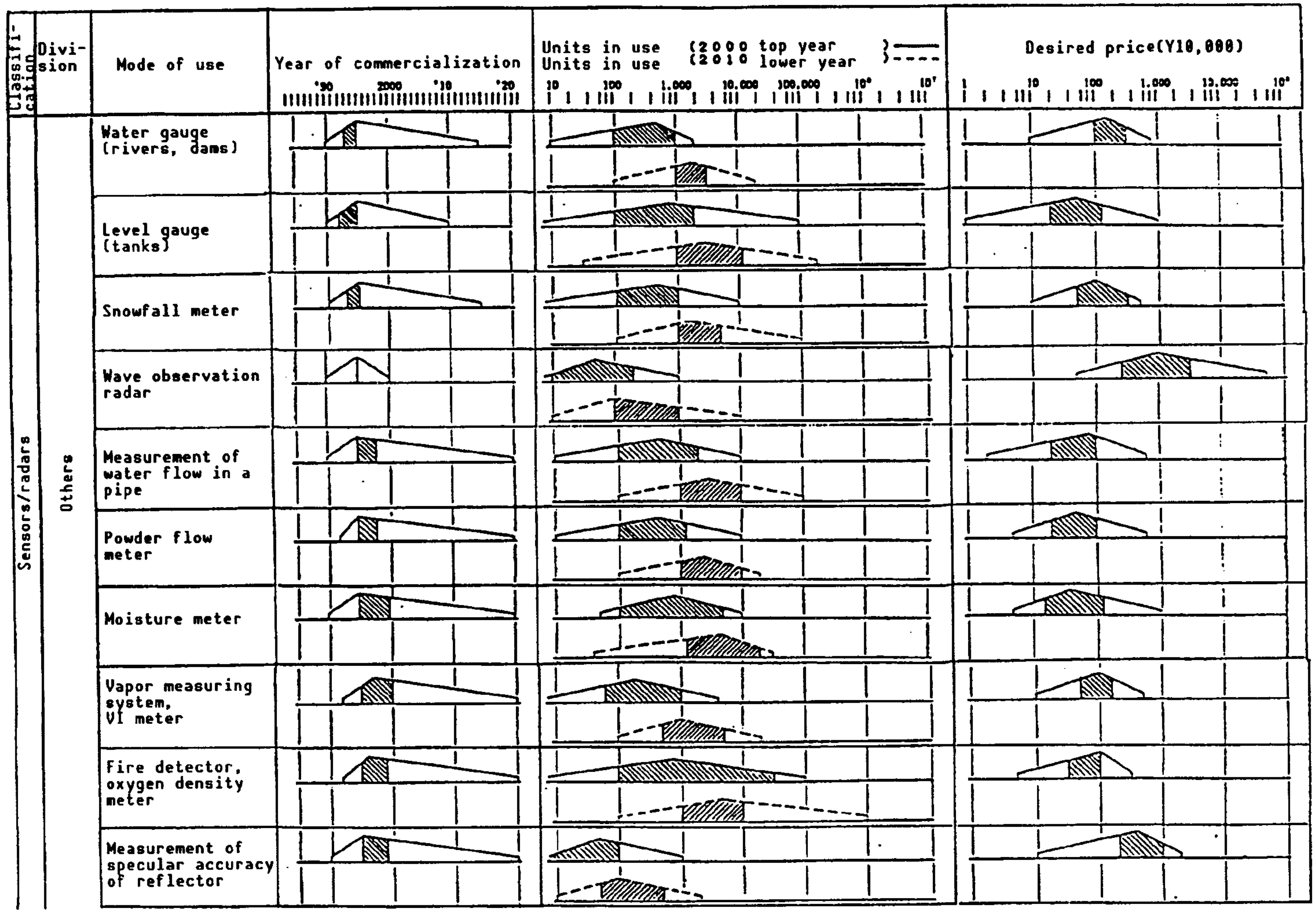
Classification
Division
Mode of use
Year of commercialization
'90
2000
'10
'20
Units in use (2000 top year) ——
Units in use (2010 lower year) - - - -
10
100
1,000
10,000
100,000
10⁶
10⁷
Desired price (¥10,000)
1
10
100
1,000
10,000
10⁵
Communications in closed space and tunnel
Two-way paging system for use in office (parent system)
〃 (subsidiary system)
POS terminal communication system
Vehicle control system (base station)
〃 (mobile station)
Mobile communications in tunnels and underground shopping malls (small, lightweight) (base station)
〃 (mobile station)
Emergency communications in underground shopping malls
Broadcasting
Small-area local broadcasting (base station)
〃 (receiver)


Classification
Division
Mode of use
Year of commercialization
'90
2000
'10
'20
Units in use (2000 top year)
Units in use (2010 lower year)
10
100
1,000
10,000
100,000
10⁶
10⁷
Desired price (Y10,000)
1
10
100
1,000
10,000
10⁵
Communications
Personal satellite communications system
Data relay between high-altitude platforms (HAPP)
Intersatellite communications (ISL)
Broadcasting
Satellite broadcasting
Radio navigation
Satellite navigation system for use by the private sector
Remote sensing
Observation of cloud thickness
Satellite-borne rainfall radar
Satellite-borne millimeter/sub-millimeter wave radiometer
Sensors/radars
Noncontact card system
Millimeter wave identification system (for persons) (card)
"
(reader)

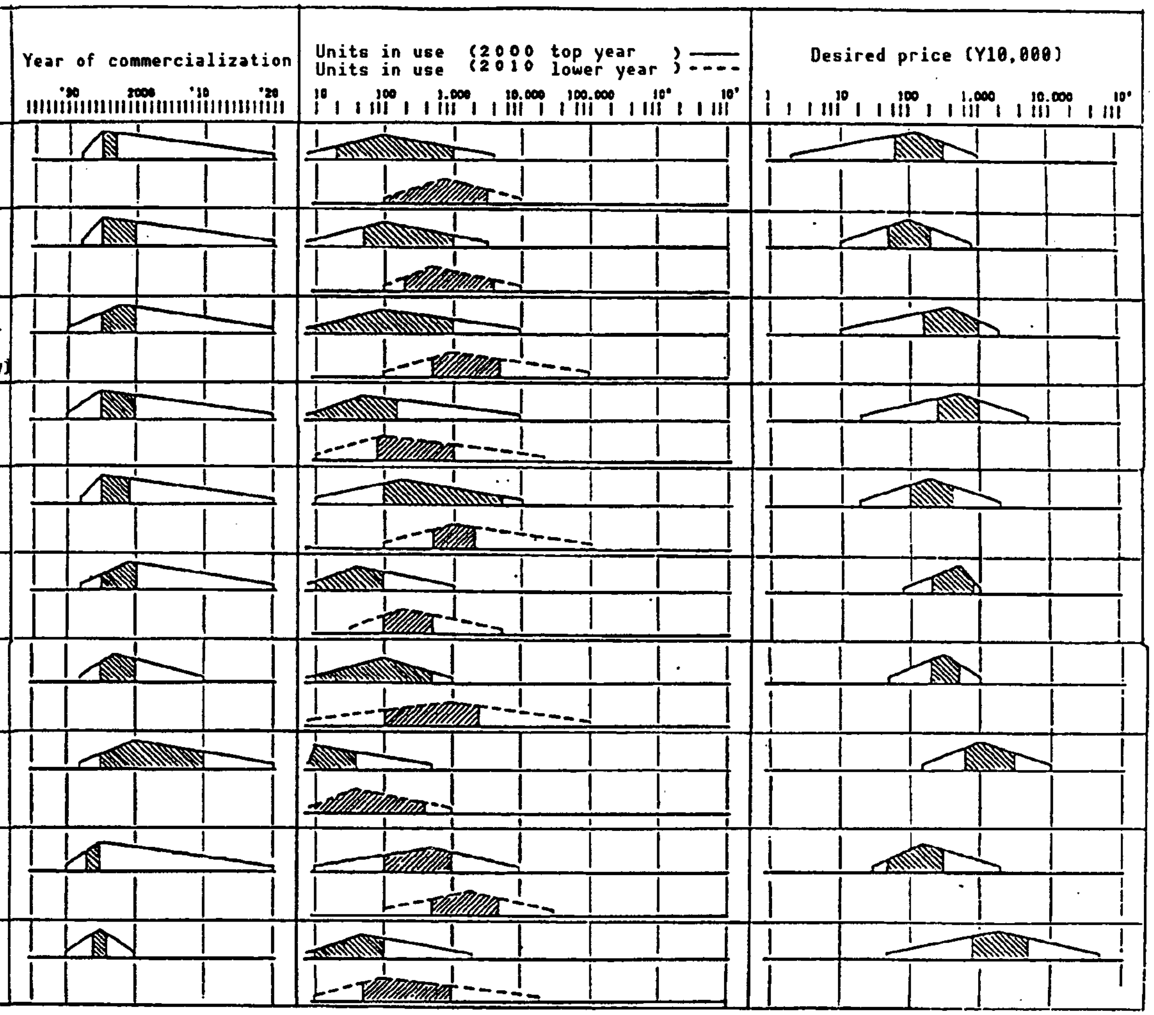

Classification
Division
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year) ——
Units in use (2010 lower year) - - - -
10 100 1,000 10,000 100,000 10^6 10^7
Desired price (¥10,000)
1 10 100 1,000 10,000 10^5
Sensors/radars
Noncontact card system
Millimeter wave identification system (for vehicles) (card)
″ (reader)
Millimeter wave identification system (for objects) (card)
″ (reader)
Noncontact IC card (card)
″ (reader)
Personal position recognition/ object probing
Personal position recognition system (base station)
″ (mobile station)
Object search system (objects, animals (in garages) (base station)
″ (mobile station)

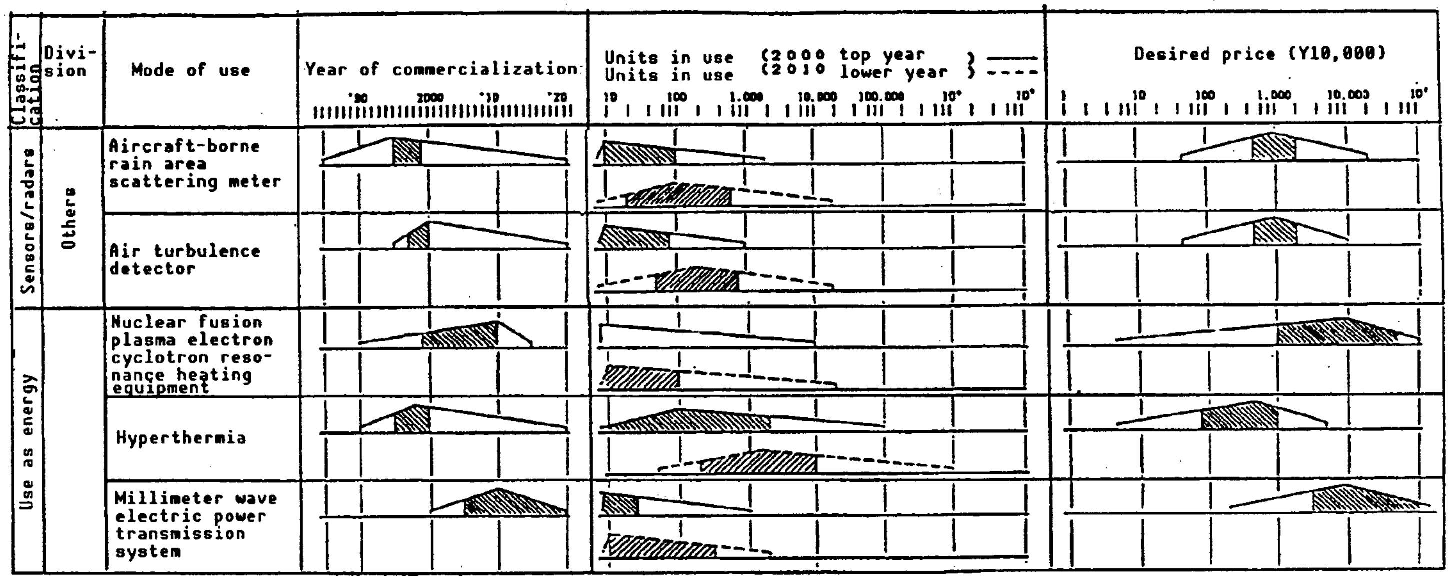

Classifi-cation
Divi-sion
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year) ——
Units in use (2010 lower year) - - - -
10 100 1,000 10,000 100,000 10⁶ 10⁷
Desired price (Y10,000)
1 10 100 1,000 10,000 10⁵
Sensors/radars
Personal position recognition/object probing
Airport surface search radar (ASDE)
Direction control system for digging machine
Obstacle detection/collision/prevention radar
Car
Obstacle detection systems for car
oCar-to-car distance warning
oCollision prevention system
Backward obstacle detection system for car
Radar for snowplows/road patrol cars (including objects buried in snow)
System for controlling distance from preceding car
Ship
Berthing system for ship
Collision prevention radar for ship
Port observation system
Aircraft
Helicopter-borne collision warning sensor


Classification
Division
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year)
Units in use (2010 lower year)
10 100 1,000 10,000 100,000 10⁶ 10⁷
Desired price (Y10,000)
1 10 100 1,000 10,000 10⁵
Sensors/radars
Aircraft
Landing aid system for helicopter
Intruder detection
Intruder detection sensor (inside, outside)
Radio wave fence (leakage cable system)
Millimeter wave fence (reflection board)
Others
Car-to-ground speed sensor (including anti-skid system)
Sensor for detecting road surface condition for car
Road profile sensor for car
Radar speedometer for speed violation control
Inspection of personal belongings including nonmetals
Landslide detection radar


Classification
Division
Mode of use
Year of commercialization
'90 2000 '10 '20
Units in use (2000 top year)
Units in use (2010 lower year)
10 100 1,000 10,000 100,000 10⁶ 10⁷
Desired price(Y10,000)
1 10 100 1,000 10,000 10⁵
Sensors/radars
Others
Water gauge (rivers, dams)
Level gauge (tanks)
Snowfall meter
Wave observation radar
Measurement of water flow in a pipe
Powder flow meter
Moisture meter
Vapor measuring system, VI meter
Fire detector, oxygen density meter
Measurement of specular accuracy of reflector

Classification	Division	Mode of use
Sensors/radars	Others	Measurement of thickness of steel plate
		Thermometer for metal plate
		Measurement for in vitro temperature (millimeter wave thermography)
		Blast furnace insert profiler
		Probing for buried pipes
		Geological survey sensor
		Radio wave/ sonic wave radar (RASS radar)
		Measurement of nuclear fusion plasma (electron density and temperature)
		Rainfall intensity meter
		Weather radar

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Units in use (2010 lower year) ----
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1,000
10,000
100,000
10⁶
10⁷
Desired price (Y10,000)
1
10
100
1,000
10,000
10⁵
Sensors/radars
Others
Aircraft-borne rain area scattering meter
Air turbulence detector
Use as energy
Nuclear fusion plasma electron cyclotron resonance heating equipment
Hyperthermia
Millimeter wave electric power transmission system

Attached Paper 1 "Members of Millimeter Wave Utilization Technology Committee"

Chairman

Takanori Ogoshi	Director of Advanced Science and Technology Center, University of Tokyo

Members

Kunio Ichimiya	Chief, Telecommunications Office, Research and Information Division, construction Economic Affairs Bureau, Ministry of Construction
Kiichi Inoue	Executive of Toyota Motor Corp. and assistant director of the company's Tokyo office
Mikio Otsuki	Executive of Fujitsu Ltd.
Tamotsu Omura	Executive of Robotech Research Institute in charge of research
Tadao Katano	Planning official, Electronic Navigation Research Institute, Ministry of Transportation
Makoto Kikuchi	Medical electronics engineering professor, National Defense Medical Academy
Takahisa Kido	Advisor to Mitsubishi Space Software Co.
Sachio Shimoseko	Chief researcher, Central Communications Laboratories (Space Communications Department), Ministry of Posts and Telecommunications
Jun Kamitsukasa	Executive of Oki Electric Industry Co., and director of company's telecommunications business
Komo Suzuki	Executive of Matsushita Communication Industrial Co.
Yoshiyuki Naito	Professor, Faculty of Engineering, Tokyo Institute of Technology
Jun Nagai	Director, Toshiba Corp., R&D Center
Hiroaki Sarada	Director, Radio System Research Laboratory, Nippon Telegraph and Telephone Co. (NTT)
Hiroshi Furukawa	Executive, Radio Wave System Development Center
Nagayuki Marumo	Executive, Nissan Motor Co.
Shigeru Miyazaki	Chief, Radio Wave Application Department, Central Communications Laboratories, Ministry of Posts and Telecommunications

Hiroshi Morikawa	Executive, Mitsubishi Electric Corp.
Kaizo Yamoto	Chief, Radio Research Department, NHK Science and Technical Research Laboratories (since December 1988)
Seijiro Yokoyama	Executive, NEC Corp. (since August 1988)
Masanobu Watanabe	Executive, Japan Radio Co.
Yuya Ito	Former executive, NEC Corp. (up until July 1988)
Junichi Yoshino	Chief, Radio Research Department, NHK Science and Technical Research Laboratories (up until November 1988)
Tatsuo Yoshiyama	Auditor, Matsushita Communication Industrial Co. (up until July 1988)

Secretariat members

Hajime Okai	Chief, Planning Division, Radio Wave Department, Telecommunications Bureau, Ministry of Posts and Telecommunications
Kaoru Suzuki	Assistant chief, Planning Division, Radio Wave Department, Telecommunications Bureau, Ministry of Posts and Telecommunications

Attached Paper No 2 "Members of Millimeter Wave Utilization Subcommittee"

Specialist members

Chief

Yoshiyuki Naito	Professor, Faculty of Engineering, Tokyo Institute of Technology

Members

Kunio Ichimiya	Chief, Telecommunications Office, Research and Information Division, Construction Economic Affairs Bureau, Ministry of Construction
Hiromitsu Okamoto	Executive, Robotech Research Institute
Tadao Katano	Official in charge of planning, Electronic Navigation Research Institute, Ministry of Transportation

Research members

Hiroshi Arai	Chief, Development Planning Office, Toyota Motor Corp.
Shigeo Aono	Director, Electronics Laboratory, Central Research Laboratories, Nissan Motor Co.
Hiroyuki Imafuku	Chief researcher, Mobile Communications Unit, Safety Systems Research Office, Railway Technical Research Institute
Takayoshi Usui	Staff member, Technical Center, SECOM Co.
Nobukazu Okubo	Chief, Communications Section, Facilities Department, Japan Highway Public Corp.
Tetsuaki Ono	Chief, Clinical M.E. Safety Research Division, Japan M.E. Society
Shizuo Kataoka	Chief, Planning Department, Mobile Communications Division, Dai-ni Den Den Co.
Haruyuki Katayama	Staff researcher, Broadcasting Technology Development Council
Minoru Uetaka	Chief, Radio Wave Utilization Research, Radio Wave Application Department, Central Communications Laboratories, Ministry of Posts and Telecommunications
Takayasu Shiokawa	Chief, Radio Transmission Research Office, Meguro Research Laboratory, KDD

Kazu Shiobara	Chief, Research and Survey Department, Radio Equipment Examination and Certification Association
Katsumi Suga	Assistant chief, Technical Planning Department, NHK
Tsuyoshi Takahashi	Chief, Equipment Development Department, Design Division, Shimizu Construction Co.
Akio Nakatsuji	Chief, Frequency Section, Planning and Management Department, National Space Development Agency
Masuo Yamamoto	Chief, Communications Technology Section, Telecommunications Department, Tokyo Electric Power Co. (since December 1988)
Shoken Yoshida	Chief researcher, Radio Systems Research Laboratory, NTT
Masayoshi Wakao	Chief, Research and Development Department, Radio Wave Systems Development Center
Minoru Aizawa	Chief, Communications Technology Section, Telecommunications Department, Tokyo Electric Power Co. (up until November 1988)

Secretariat members

Kaoru Suzuki	Assistant chief, Planning Division, Radio Wave Department, Telecommunications Bureau, Ministry of Posts and Telecommunications
Yoichi Yano	First Subsection chief, Planning Division, Radio Wave Department, Telecommunications Bureau, Ministry of Posts and Telecommunications
Chihaya Kato	First Frequency Subsection chief, Planning Division, Radio Wave Department, Telecommunications Bureau, Ministry of Posts and Telecommunications

Attached Paper 3 "Members of Millimeter Wave Technology Development Subcommittee"

Chief specialist member

Shigeru Miyazaki	Chief, Radio Wave Application Department, Central Communications Laboratories, Ministry of Posts and Telecommunications
Hiromitsu Okamoto	Executive, Robotech Research Institute

Research members

Hisashi Iida	Chief researcher, Satellite Development Division, National Space Development Agency
Kenichi Okamoto	Chief, Atmospheric Propagation Research Office, Central Communications Laboratories, Ministry of Posts and Telecommunications
Takurao Oguchi	Satellite Business Department, Transmission and Radio Wave Division, Fujitsu Ltd.
Sachio Suzuki	Chief, Radio Wave Business Division, Toshiba Corp.
Tatsuo Takayanagi	Chief, Satellite Project Promotion, Transmission Radio Wave Business Department, Telecommunications Division, Oki Electric Industry Co.
Sachio Takimoto	Chief in charge of R&D Sensor Development and Promotion Division, NEC Corp.
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Yokichi Hirota	Chief, No 6 Section, Technical Department, Kamakura works, Mitsubishi Electric Corp.
Norihiko Yazawa	Chief researcher, Radio Research Department, NHK Science and Technical Research Laboratories
Kazuo Yamashita	Assistant director, Research Institute, Japan Radio Co.
Shoken Yoshida	Chief researcher, Radio Systems Research Lab., NTT
Masayoshi Wakao	Chief, Research and Development Department, Radio Wave Systems Development Center

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Kaoru Suzuki
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